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RESEARCH NEEDS FOR IRRIGATION RETURN FLOW QUALITY CONTROL

Gaylord V. Skogerboe, et al

Robert S. Kerr Water Research Center
Ada, Oklahoma

November 1971

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U.S. ENVIRONMENTAL PROTECTION AGENCY

RESEARCH NEEDS FOR IRRIGATION RETURN FLOW QUALITY CONTROL

by

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for the

OFFICE OF RESEARCH AND MONITORING
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ABSTRACT

There are a number of potential solutions for controlling the quantity and quality of irrigation return flow. Using efficient practices in the delivery canals and pipelines, as well as improving on-the-farm water management, will minimize the problems in the water removal system. In most cases, the key to minimizing irrigation return flow quality problems is to improve water management practices on the croplands.

There are various institutional methods which can be used to control irrigation return flow quality. These methods include restricting irrigation development in areas of potentially high salt pickup, regulations on the use of fertilizers, or agricultural chemicals, tailwater controls which would not allow surface runoff from a farm, increasing water rate charges, changing the interpretation of western water laws, use of irrigation scheduling to overcome institutional constraints, consolidation of irrigation companies in an irrigated valley into a single management unit, and/or requiring that anyone degrading the quality of water pay the cost of treating this water.

There are a multitude of research needs regarding irrigation return flow quality, but only the specific research needs required to undertake an effective control program are described. These research needs include irrigation practices, soil-plant-salinity relationships, leaching requirements, prediction of subsurface return flow, cultural practices, irrigation scheduling, treatment of return flows, economic evaluations, and institutional control methods.

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SECTION I

CONCLUSIONS

The practice of irrigation has detrimental effects on environmental water quality, just as do many other of man's activities. Usually, the quality of water draining from irrigated areas is materially degraded in several ways as compared with the water applied. However, irrigation can also produce beneficial water quality effects through denitrification, phosphate reduction in subsurface return flows, and biological improvements. Irrigation return flows are of special concern because irrigated agriculture is the largest consumer of our water resources.

At the present time, about 48 million acres of land are irrigated in the United States, with all but 5 million acres being located in the 17 western states. Crop production is reduced on one-quarter of the irrigated lands due to saline soils, while salinity is an immediate hazard to half of these irrigated lands. Throughout the world, a third of the irrigated land is plagued by salt problems.

The major water quality problem resulting from irrigated agriculture is the salt transported to groundwater reservoirs and rivers by irrigation return flow. Other problems include the movement of sediments, variable amounts of fertilizers and pesticides, phosphates (which may come from fertilizers), and increased bacterial content in surface return flows. Subsurface return flows frequently show considerable increase in salts, including nitrates, but show a reduction in bacteria.

Presently, the major irrigation return flow quality problem areas are the San Joaquin Valley, Colorado River Basin, and Rio Grande Basin. Of these three areas, only the Colorado River Basin has had a reconnaissance study undertaken to determine the salinity sources and to define, in a general manner, potential control measures. Studies on irrigation return flow have been conducted in the San Joaquin Valley, while very little attention has been given to irrigation return flow in the Rio Grande Basin. In addition to these major problem areas, there are numerous other locations throughout the West with recognized irrigation return flow problems, including the Yakima Valley in Washington; the Carson and Humboldt rivers in Nevada; the Santa Ana River

Basin in California; the Sevier River in Utah; the South Platte River in Colorado; the Bear River in Utah and Idaho; the Platte River in Nebraska; the Pecos River in New Mexico and Texas; the Columbia River Basin in Idaho, Oregon, and Washington; and the Arkansas River Basin in Colorado, Kansas, Oklahoma, and Arkansas. Actually, potential water quality problems exist wherever irrigation is practiced.

Practical means for alleviating and/or controlling water quality degradation of surface and groundwater resources resulting from irrigated agriculture must be developed. Where control measures are not readily apparent, research is needed to develop criteria for effective solutions. A unified research and development program requires careful planning, which includes defining specific research activities necessary for the successful implementation of control programs.

There are a number of potential solutions for controlling the quantity and quality of irrigation return flow. The irrigation system can be subdivided into the water delivery subsystem, the farm, and the water removal sub-system. Using efficient practices in the delivery canals and pipelines, as well as improving on-the-farm water management, will minimize the problems in the water removal system. In most cases, the key to minimizing irrigation return flow quality problems is to improve water management practices on the croplands.

The water delivery system can be improved by lining canals and laterals, using closed conduits for water transportation, providing adequate control structures, and installing flow measuring devices.

Improved practices that can be used on the farm include judicious use and application, or placement, of fertilizers, use of slow-release fertilizers, controlling water deliveries across the farm, use of improved irrigation application methods (e.g. subsurface application of trickle irrigation), control of soil evaporation, use of a pumpback system to allow recycling of surface return flows, erosion control practices (e.g. contour farming), and irrigation scheduling to insure that the proper amounts of water are applied at the times required by the plants.

In the water removal sub-system, open drains and tile drainage can be used to collect return flows, which can then be subjected to treatment on a large area or basin-wide basis, if necessary.

There are various institutional methods which can be used to control irrigation return flow quality. These methods include restricting irrigation development in areas of potentially high salt pickup, regulations on the use of fertilizers, or agricultural chemicals, tailwater controls which would not allow surface runoff from a farm, increasing water rate charges, changing the interpretation of western water laws, use of irrigation scheduling to overcome institutional constraints, consolidation of irrigation companies in an irrigated valley into a single management unit, and/or requiring that anyone degrading the quality of water pay the cost of treating this water.

There are a multitude of research needs regarding irrigation return flow quality, but only the specific research needs required to undertake an effective control program are described. These research needs include irrigation practices, soil-plant-salinity relationships, leaching requirements, prediction of subsurface return flow, cultural practices, irrigation scheduling, treatment of return flows, economic evaluations, and institutional control methods.

SECTION II

RECOMMENDATIONS

A study of the Rio Grande Basin should be undertaken to define the magnitude of the water quality problems within the basin. Potential solutions, and their associated costs, for controlling quality degradation should be evaluated.

The two major areas of research which would facilitate the development of control programs for an area are: (a) subsurface return flow quality prediction techniques; and (b) economic evaluation. Without this research, a control program is severely hampered because the effects of imposing changes upon the system, such as control measures, cannot be adequately evaluated.

Research projects should be initiated to develop and recommend quality control measures for subsurface return flow in the Colorado River Basin and Rio Grande Basin, while additional studies are needed in the San Joaquin Valley. These same three study areas used to develop prediction techniques for subsurface return flows should be used for research and demonstration projects regarding irrigation practices, soil-plant-salinity relationships, cultural practices, leaching requirements, irrigation scheduling, and drainage water treatment.

An economic evaluation of costs and benefits from return flow control programs should be undertaken for each of these three major problem areas. The research and demonstration activities should be coordinated into the control program for each region. A strong interaction must exist between the research teams and local and action agency personnel. Research teams should consist of regional, state, and federal personnel most capable of developing control programs.

A study should be undertaken to evaluate the feasibility of changing the interpretation of western water laws to provide incentives for efficient water management on irrigated lands.

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The soil and water conservation measures proven over the past few decades to have water quality benefits, e.g., soil erosion control, canal and farm ditch lining, and improved irrigation practices, should continue through educational and action programs.

The institutional constraints to water management reform in irrigated areas should be critically evaluated. Major among these are water rights doctrine and management practices of mutual water districts, canal companies, etc. The effects of negotiable rather than fixed water rights should be investigated, in addition to the effect of including quality as well as quantity to water rights.

Federal legislation should be enacted to provide economic incentives to undertake irrigation return flow quality control projects.

SECTION III

INTRODUCTION

Irrigation is one of the most important agricultural practices developed by man, with irrigation being practiced in some form since the earliest recorded history of agriculture. The economic base for many ancient civilizations was provided by irrigation. Indians of the western hemisphere were irrigating crops long before the discovery of the New World (25). Much of the economy of the western United States depends on irrigation, which has been the dominant factor in the development of land and water resources in the arid and semi-arid regions of the western states. Irrigation is practiced on about 10 percent of the total cropped land in the United States, but this land produces approximately 25 percent of the Nation's total crop value (20). Irrigation farming not only increases productivity, but it also provides flexibility which allows shifting from the relatively few dryland crops to many other crops which may be in greater demand. Irrigation contributes to strengthening other facets of a region's economy in that it creates employment opportunities in the processing and marketing of agricultural products.

The practice of irrigation has detrimental effects on environmental water quality, just as do many other of man's activities. It has long been recognized that the quality of water draining from irrigated areas was materially degraded from that of the irrigation water applied. Agriculturists have viewed this as a natural consequence of the many processes involved, and little attention has been given to the possibility that progress could be made toward controlling or alleviating the quality degradation caused to our water resources. Recent Federal Legislation and a greatly increased national concern have reversed this attitude, and we have been charged "to establish a national policy for the prevention, control, and abatement of water pollution" (14). The Water Quality Act of 1965 further provided for all states to establish water quality standards for their interstate and coastal waters. Crucial decisions were required regarding the uses of water resources, quality criteria to support these uses, and specific plans for achieving such levels of quality. The purpose of this program is to enhance the quality and value of polluted water and to protect the quality of clean water. The water quality standards are, in effect, the guides to an effective clean water program. Although the major efforts to date appear to be in the treatment and control

of municipal and industrial wastes, agriculture is by no means exempted from the fight against water quality degradation. The water quality problems associated with irrigation return flows are of special concern because irrigation agriculture is the largest consumer of our Nation's water resources. It is also of major importance to the economy of a large segment of the nation and is the supplier of a significant part of the food and fiber produced annually.

Irrigation return flow constitutes a large portion of the flow in many streams of the western United States. Some degree of salt concentration due to irrigation has been accepted as the price for irrigation development. However, there are areas where quality degradation has been a serious matter for some time. As pressures on water resources increase, there is a mounting concern for proper control of such serious water quality deterioration. The need for more precise information as a basis for wise action has been brought sharply into focus. There is a great dearth of information concerning the exact role of irrigation return flows in surface and groundwater quality problems.

Irrigation Return Flow System

The complexities of the irrigation return flow system and its relationship to a river basin are portrayed schematically in Figure 1. The model shows the primary sources of return flow to be canal seepage, bypass water, deep percolation, groundwater flow, and tailwater or surface return flow. Each of these can be subjected to some degree of manipulation and/or control through water management techniques. Bypass water is chiefly a water resource or conservation problem, since few impurities are added by simply flowing through the canal system. It is required for the purpose of maintaining head and adequate flow through the canal system and is usually returned directly to the river. Canal seepage, on the other hand, contributes to high water tables, aggravates subsurface salinity, encourages phreatophyte growth, and generally increases saline subsurface drainage from irrigated areas. Canal seepage can be a significant fraction of the total diversion in many project areas (30). Once water is applied to irrigated cropland, tailwater and deep percolation are the major contributors to irrigation return flow. These sources are the conveyors of dissolved salts, plant nutrients, sediments, pesticides, and other pollutants to the stream drainage system.

The diversion-return flow cycle shown in Figure 1 is typical of many western rivers. The flow at any point in the river may be composed of natural inflow, irrigation return flow, municipal and industrial effluents, and return flow of other used water. The proportion of each depends on such factors

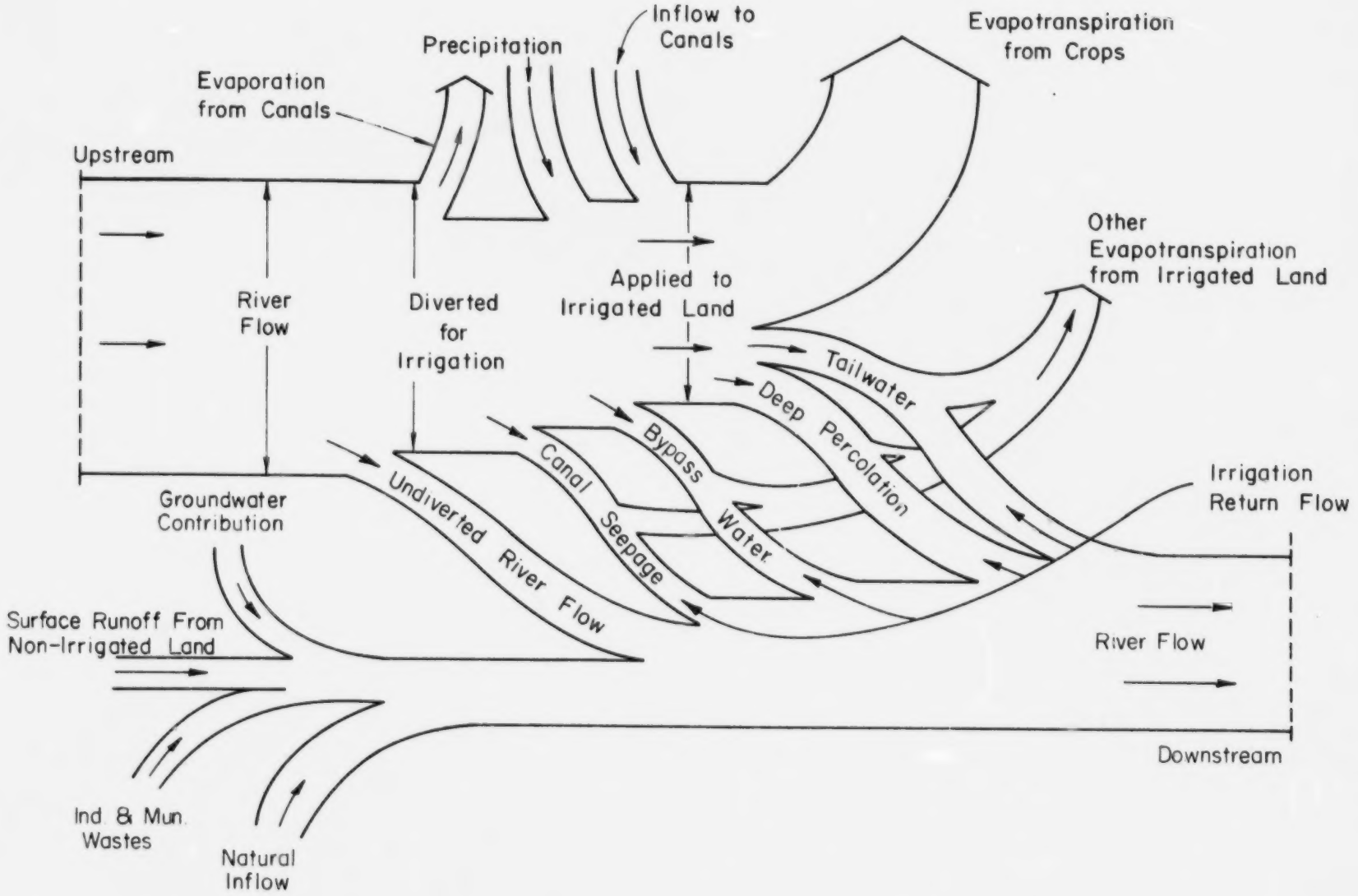

Figure 1. Model of the irrigation return flow system.

as the number of diversions, the extent and diversity of uses, the position on the stream, and the amount of natural inflow to the stream. The model represents but one diversion cycle which may be repeated many times over in a river basin.

The major water quality problems resulting from irrigation are due to the basic fact that plants are large consumers of water resources. Growing plants extract water from the supply and leave salts behind, resulting in a concentration of the dissolved mineral salts which are present in all natural water resources. In addition to having greater concentrations of salts in the return flow resulting from evapotranspiration, irrigation also adds to the salt load by leaching natural salts arising from weathered minerals occurring in the soil profile, or deposited below. Irrigation return flows provide the vehicle for conveying the concentrated salts and other pollutants to a receiving stream or groundwater reservoir. It is necessary to examine the water quality problems resulting from this process and to develop and implement measures to control or alleviate the detrimental effects.

Purpose of Report

The responsibility for developing and coordinating the national Irrigation Return Flow Research and Development program within the Environmental Protection Agency is vested in the Robert S. Kerr Water Research Center at Ada, Oklahoma. Briefly, the major goal of the program is to find practical and economically feasible means to alleviate and/or control the water quality degradation of surface and groundwater resources resulting from irrigated agriculture. In establishing and implementing such a broad control program, a number of decision-making steps are required. First of all, decisions are required on effective control measures required by the program. Where control measures are not readily apparent, the second step requires specifying the research that is needed to identify, verify, and/or justify certain control measures that would be effective in accomplishing the program goals. Finally, investigations, demonstrations, and applied research will be required to solve the social, legal, and institutional problems inherent in effecting the necessary changes to bring about quality control of irrigation return flows.

A unified research and development program requires careful planning. There is a need to define in some detail the research activities required by the program. This report is an effort to meet this immediate need. Under the terms of an existing grant agreement with the Department of Agricultural Engineering at Colorado State University, basic

background information for the report was gathered. Recognized authorities in several of the western states were visited and interviewed (See Section IX Acknowledgments). The results of those interviews constitute the basis for the majority of the material presented herein.

The objectives of the report are specified by the major topics covered as follows:

a. Define the major geographic areas where irrigation return flow problems exist.

b. Specify the major water quality problems arising from irrigation return flows and how these differ by regions.

c. Propose potential solutions required to alleviate and/or control water quality degradation by irrigation.

d. Define specific research activities most urgently required to design and implement control measures or potential solutions to critical problems.

This report will form the basis for future program planning. It will provide specific problem definitions needed to develop an integrated program for achieving solutions needed to establish guidelines for the control of water quality of irrigation return flows. In addition to the program planning function, it will serve as a guide to interested research groups.

SECTION IV

MAJOR AREAS FOR IRRIGATION RETURN FLOW PROBLEMS

In the past 80 years, the total irrigated land in the United States has increased from under four million acres to over 48 million acres, or an increase of 1,200 percent. During the last two decades, the value of supplemental irrigation has been recognized in the humid eastern United States, with the total irrigated acreage being five million acres. There is reason to believe that the acreage of irrigated lands will continue to increase. At the same time, farming is becoming more and more intensive, thereby resulting in greater food production on each acre of irrigated cropland, with increasing use of fertilizers.

Every state has some croplands which are irrigated. A tabulation of irrigated acreages during 1968 and 1969 for each state (29) is listed in Table 1, while the amount of irrigated land for 1959 and 1969 (22,28) is given in Table 2 by river basins. There is a discrepancy between Tables 1 and 2 regarding the 1969 irrigated acreage, which amounts to roughly 5 million acres, or 10 percent. The major irrigated areas in the United States are located in the seventeen western states. Both California and Texas contain more than eight million acres of irrigated land, with Nebraska having more than four million irrigated acres, and Colorado, Idaho, and Montana each containing better than three million irrigated acres. The major river basins are shown in Figure 2.

The Economic Research Service (22) has made projections of irrigated acreage in the United States to the year 2020. A breakdown of these projections by major river basins is shown in Table 3. The increase in irrigated acreage in the United States (mainland 48 states) from 1969 to 2000 is roughly 30 percent, with the projected increase for the same time period in the western states being 25 percent.

Many of the irrigated lands, particularly in western arid areas, contain large quantities of salt and are therefore classed as saline soils. Some lands are high in exchangeable sodium and are referred to as being sodic. The estimated acreage of salt-affected soils is listed in Table 4 (30). Crop production is reduced on one-quarter of the irrigated lands in the western United States due to saline soils. Salinity is a hazard to half of the

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Table 1. U.S. irrigated acreage by states for 1968 and 1969 (29).

State	Irrigated Acreage 1968	Irrigated Acreage 1969	Percent Increase or Decrease
Alabama	32,000	32,000	0
Alaska	464	1,155	+149
Arizona	1,131,000	1,145,000	+ 1
Arkansas	1,350,000	1,435,000	+ 6
California	8,600,000	8,500,000	- 1
Colorado	3,280,000	3,310,000	+ 1
Connecticut	13,000	12,000	- 8
Delaware	14,700	14,700	0
Florida	1,440,876	1,490,876	+ 3
Georgia	182,000	144,629	- 26
Hawaii	126,000	126,000	0
Idaho	3,660,000	3,660,000	0
Illinois	32,000	34,000	+ 6
Indiana	34,400	35,100	+ 2
Iowa	93,000	95,000	+ 2
Kansas	1,416,814	1,588,377	+ 5
Kentucky	21,000	21,000	0
Louisiana	580,687	580,687	0
Maine	6,574	14,772	+125
Maryland	23,000	23,000	0
Massachusetts	29,470	30,470	+ 3
Michigan	138,000	139,000	+ 1
Minnesota	25,000	25,000	0
Mississippi	115,000	209,057	+ 82
Missouri	145,305	145,305	0
Montana	3,200,000	3,200,000	0
Nebraska	4,103,300	4,236,000	+ 3
Nevada	1,300,000	1,300,000	0
New Hampshire	3,100	3,100	0
New Jersey	96,439	106,300	+ 10
New Mexico	875,000	1,000,000	+ 4
New York	87,500	89,250	+ 2
North Carolina	104,029	104,639	0
North Dakota	89,100	89,100	0
Ohio	36,000	37,000	+ 3

Table 1. (Continued)

State	Irrigated Acreage 1968	Irrigated Acreage 1969	Percent Increase or Decrease
Oklahoma	610,000	619,278	+ 3
Oregon	1,760,000	1,800,000	+ 2
Pennsylvania	37,000	37,000	0
Rhode Island	3,325	3,325	0
South Carolina	35,618	37,772	+ 5½
South Dakota	414,000	414,000	0
Tennessee	17,500	17,250	- 1
Texas	8,300,000	8,200,000	- 1
Utah	1,348,624	1,348,624	0
Vermont	2,200	2,200	0
Virginia	65,000	50,000	- 30
Washington	1,440,000	1,460,000	+ 1
West Virginia	3,060	3,313	+ 8
Wisconsin	110,000	110,000	0
Wyoming	1,608,500	1,642,500	+ 2
U.S. Total	48,311,148	48,551,216	+ ½
17 Western States	43,307,901	43,341,316	0
Other States	5,003,247	5,209,900	+ 4

Table 2. Irrigated acreage by major hydrologic regions in the United States for 1959 and 1969.

	1959[1] Acres 1,000	1969[2] Acres 1,000
North Atlantic	208	519
South Atlantic - Gulf	560	1,747
Great Lakes	82	143
Ohio Basin	30	99
Tennessee Basin	13	18
Upper Mississippi	55	121
Lower Mississippi	625	972
TOTAL-EASTERN REGIONS	1,573	3,619
Souris - Red - Rainy	9	20
Missouri Basin	5,802	6,985
Arkansas - White - Red	2,806	5,357
Texas - Gulf	4,168	5,890
Rio Grande	1,638	2,020
Upper Colorado	1,361	1,700
Lower Colorado	1,219	1,430
Great Basin	1,426	2,240
Columbia - North Pacific	5,014	5,815
California	7,627	8,050
TOTAL-WESTERN REGIONS	31,070	39,507
MAINLAND UNITED STATES	32,643	43,126

[1] Tabulated by river basins from the 1959 USDA Census of Agriculture (28).

[2] Taken from projections by George A. Pavelis, Economic Research Service, USDA (22).

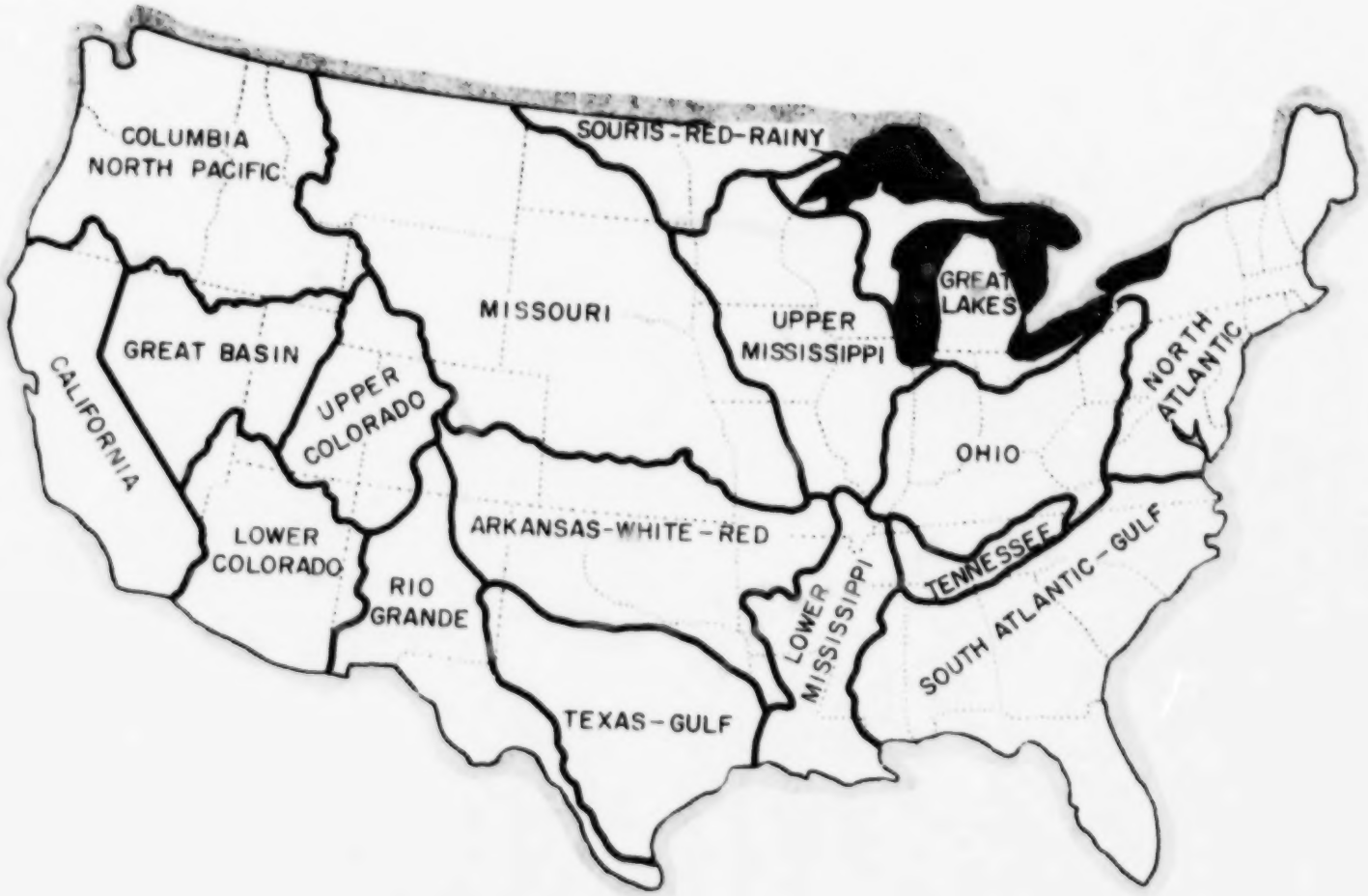

Figure 2. Major hydrologic regions in the United States

Table 3. Long-term projective estimates of agricultural irrigation in the United States, from 1980 to 2020 (22). (All acreage data are in thousands of acres.)

	1980	2000	2020
North Atlantic	730	990	1,120
South Atlantic - Gulf	2,480	3,520	4,150
Great Lakes	230	350	470
Ohio Basin	150	250	340
Tennessee Basin	30	50	70
Upper Mississippi	210	310	410
Lower Mississippi	1,400	2,070	2,570
TOTAL-EASTERN REGIONS	5,230	7,540	9,130
Souris - Red - Rainy	90	230	250
Missouri Basin	8,050	8,950	9,600
Arkansas - White - Red	5,600	6,400	6,690
Texas Gulf	6,510	7,350	7,770
Rio Grande	2,050	2,180	2,200
Upper Colorado	1,900	2,150	2,250
Lower Colorado	1,820	2,190	2,400
Great Basin	2,340	2,510	2,570
Columbia - North Pacific	7,350	7,810	8,490
California	9,050	9,600	11,540
TOTAL-WESTERN REGIONS	44,760	49,370	53,760
MAINLAND UNITED STATES	49,990	56,910	62,890

Table 4. Status and extent of saline and sodic areas in the seventeen western states and Hawaii, 1960.[1]

State	Area reported	Total acreage[2]	Salt-free		Saline-all classes	
			Acres	%	Acres	%
Arizona	Statewide	1,565,000	1,166,170	74.5	398,830	25.5
California	Statewide	11,500,000	7,755,049	67.4	3,744,951	32.6
Colorado	Statewide	2,811,532	1,829,704	65.1	981,828	34.9
Hawaii	7 areas	117,418	71,868	61.2	45,550	38.8
Idaho	All but 3 counties	1,880,063	1,627,118	86.5	252,945	13.5
Kansas	Statewide	421,545	319,215	75.7	102,330	24.3
Montana	4 areas	1,242,728[3]	1,045,057	84.1	197,671	15.9
Nebraska	Statewide	1,218,385	928,385	76.2	290,000	23.8
Nevada	Statewide	1,121,916	646,316	57.6	475,600	42.4
New Mexico	Statewide	850,000	659,000	77.5	191,000	22.5
North Dakota	6 areas	2,636,500[3]	1,819,870	69.0	816,630	31.0
Oklahoma	Statewide	826,650	632,900	76.6	193,750	23.4
Oregon	Statewide	1,490,394	1,387,033	93.1	103,361	6.9
South Dakota	Statewide	1,697,974	501,708	29.5	1,196,266	70.5
Texas	4 areas	2,198,950	1,923,096	87.5	275,854	12.5
Utah	7 areas	1,390,222	877,440	61.1	512,782	36.9
Washington	23 counties and the Columbia Basin	2,221,484	1,955,230	88.0	266,254	12.0
Wyoming	Statewide	1,261,132	981,429	77.8	279,703	22.2
TOTAL		36,451,893	26,126,588	71.6	10,325,305	28.4

[1] Unpublished data from the U.S. Salinity Laboratory cited in "Characteristics and Pollution Problems of Irrigation Return Flow," Utah State University Foundation (1969).

[2] Irrigable

[3] Arable

irrigated acreage in the West. California, which has a greater acreage of irrigated land than any other state, also contains the largest acreage of salt-affected soils. The states of South Dakota, Nevada, Hawaii, Utah, and Colorado have more than one-third of the irrigated lands being affected by highly saline soils.

The impaired crop production previously mentioned is not limited to the western United States, but is a major problem in many areas of the world. The portions of the world facing the greatest population pressures are the same areas which have the least amount of additional land available for agriculture. In such areas, increased food production must come from more intensive farming with consequent increased yields. Although there is a great need to increase the productivity of such lands, agricultural production is being damaged due to rising groundwater tables and increased salinity in the soils and groundwater supplies. Bower (4) has estimated that more than a third of the world's irrigated land is plagued by salt problems.

Projected water demands in the United States for the year 2000 are shown in Table 5 for major types of water uses (9). The total diversion, depletion, and return flows for irrigation, municipal, manufacturing, mining, and power plant cooling are shown for the years 1954 and 2000. The projected increase in irrigation diversions is very small, with such diversions increasing 5 percent, while the increase in irrigated acreage from 1954 to 2000 is projected to be doubled. Thus, the projections for water withdrawals reflect an expected major increase in irrigation efficiency.

The National Academy of Sciences (9) has made projections for irrigation water requirements based on current water use efficiencies and estimated future efficiencies as shown in Table 6. For the western region, improved water use efficiency would result in a net decrease of surface water withdrawals.

Table 5. Estimated diversions, depletions, and return flows by major water uses in the United States for the years 1954 and 2000 (9). (All units in billions of gallons daily.)

	Year 1954			Year 2000		
Use	Gross Withdrawal	Consumptive Use	Return	Gross Withdrawal	Consumptive Use	Return
Irrigation	176.1	103.9	72.2	184.5	126.3	58.2
Municipal	16.7	2.1	14.6	42.2	5.5	36.7
Manufacturing	31.9	2.8	29.1	229.2	20.8	208.4
Mining	1.5	0.3	1.2	3.4	0.7	2.7
Steam-Electric Power Cooling	74.1	0.4	73.7	429.4	2.9	426.5
Totals	300.3	109.5	190.8	888.7	156.2	732.5

Notes:

Withdrawals and consumptive uses from Report of the Select Committee on National Water Resources, 86th Congress, January 30, 1961.

Total estimated streamflow = 1,100 billion gallons daily.

Table 6. Estimated annual irrigation water requirements for years 1957, 1980, and 2000 (9). (All units in thousands of acre-feet.)

Water Resource Region	Total groundwater and surface-water requirements					Surface-water requirement at estimated future efficiency			Additional surface-water requirement at estimated future efficiency	
	At current efficiency[a]			At estimated future efficiency						
	1957[b]	1980	2000	1980	2000	1957	1980	2000	1980	2000
Eastern:										
New England	54	96	297	80	247	49	73	225	24	176
Delaware-Hudson	220	312	583	292	437	110	146	219	36	109
Chesapeake Bay	84	156	1,675	132	1,256	77	121	1,156	44	1,079
Southeast	1,743	3,022	12,196	2,374	8,711	906	1,234	4,530	328	3,624
Eastern Great Lakes	44	66	713	54	546	32	39	399	7	367
Western Great Lakes	67	142	1,330	120	997	58	103	857	45	799
Ohio	84	186	2,178	158	1,633	59	111	1,143	52	1,084
Cumberland	8	11	113	9	85	7	9	78	1	71
Tennessee	44	60	354	57	275	40	52	253	12	213
Upper Mississippi	100	243	6,081	212	4,561	56	119	2,554	63	2,488
Lower Mississippi	1,592	2,295	4,409	2,020	3,351	605	768	1,273	163	668
Lower Missouri	21	45	1,650	39	1,350	18	34	1,161	16	1,143
Lower Arkansas, White, Red	1,560	2,177	3,847	1,880	3,148	437	526	881	89	444
Subtotal	5,621	8,811	35,426	7,427	26,597	2,454	3,334	14,729	880	12,275
Western:										
Upper Missouri	17,717	20,747	32,040	16,346	22,331	15,237	14,058	19,205	- 1,179[c]	3,968
Upper Arkansas, White, Red	4,748	4,876	6,488	4,035	4,922	1,329	1,130	1,378	- 199	49
Western Gulf	11,840	11,789	15,689	9,226	10,914	5,328	4,613	6,003	- 715	675
Upper Rio Grande-Pecos	6,576	7,079	8,053	5,522	5,315	2,959	2,761	2,923	- 198	- 36[c]
Colorado	20,262	20,335	20,708	16,071	14,696	14,386	12,214	11,904	- 2,172	-2,482
Great Basin	9,444	9,481	9,742	7,449	6,727	8,216	6,481	5,852	- 1,735	-2,364
Pacific Northwest	16,182	16,837	21,053	13,680	15,132	14,887	12,586	13,921	- 2,301	- 966
Central Pacific	35,924	35,031	35,623	30,223	27,241	17,962	16,623	16,345	- 1,339	-1,617
South Pacific	5,044	4,486	4,635	3,671	3,371	2,522	2,019	2,023	- 503	- 499
Subtotal	127,737	130,661	154,031	106,223	110,649	82,826	72,485	79,554	-10,341[c]	-3,272[c]
United States Totals	133,358	139,472	189,457	113,650	137,246	85,280	75,819	94,283	- 9,461[c]	9,003

[a] Assuming no increase in efficiency of application and transmission of irrigation water.

[b] Based on adequate irrigation of all land under irrigation.

[c] Negative values indicate a net decrease in water requirements resulting from estimated increased efficiency in use and transmission of irrigation water.

Whenever water is diverted from a river for irrigation use, the quality of the return flow is degraded. The return flow mixes with the natural flows in the river. This mixture is then available to downstream users to be diverted to satisfy their water demands. This process of diversion and return flow may be repeated many times along the course of a river. In the case of the original diversion, if the increase in pollutants contained in the return flow is small in comparison to the total flow in the river, the water quality would probably not be degraded to such an extent that it would be unfit for use by the next downstream user.

If the quantity of pollutants in the return flow is large in relation to the river flow, then it is very likely that the water is not suitable for the next user unless the water is treated to remove objectionable constituents. Since water is diverted many times from the major rivers, the river flows show a continual degradation of quality in the downstream direction. As the water resources become more fully developed and utilized, without controls, the quality in the lower reaches of the river will likely be degraded to such a point that the remaining flows will be unsuitable for many uses, or previous uses of the waters arriving at the lower river basin no longer will be possible.

Two examples of major river basins having high utilization of the water resources and experiencing deleterious water quality effects are the Colorado River Basin and the Rio Grande Basin. The water users in the Lower Colorado River Basin, especially Mexico, the Imperial, and Coachella valleys, experience difficulties at the present time due to high salt concentrations in the river. Salt concentrations in the Lower Colorado River at the turn of the century (year 2000) due to anticipated water resource development projects are projected to increase. Projects are presently nearing completion for exporting additional quantities of high quality water from Colorado River watersheds to satisfy water demands in the more populous regions of Utah, Colorado, and New Mexico. The authorized Central Arizona Project will divert large quantities of flow from the Colorado River to Salt River Valley, which is within the basin, but the return flows to the Colorado River will be almost nil. However, the irrigation return flows will have long-term effects on the salt balance in the Salt River Valley. In addition, large quantities of water will be diverted, with no return flows, for use by present and future power plants in the four corners region (Utah, Colorado, New Mexico, and Arizona). A salinity control program, which would be a combination of controlling mineralized springs and irrigation return flows, would negate a large portion

of the damage which will result from recently constructed and anticipated water resource development projects, which will export good quality water to adjacent river basins, thereby leaving less water within the Colorado River Basin for diluting irrigation return flows.

The Rio Grande Basin is another example of an area already experiencing serious water quality problems, with the outlook for even more serious problems. Rapid population growths in Albuquerque, El Paso, and Juarez, alone, foretell of immediate difficulties. Whereas studies have been made in the Colorado River Basin which predict future water quality problems due to basin development, such comprehensive studies have not been undertaken in the Rio Grande River Basin. Future water quality problems in this basin could easily result in international problems somewhat similar to those recently experienced in the Lower Colorado River. By necessity, a control program for irrigation return flow would be a significant part of any comprehensive water development plan.

Another major irrigated agricultural area which is presently experiencing water quality problems due to irrigation return flow is the San Joaquin Valley. Water deliveries from portions of the recently constructed California State Water Project have begun. New lands are being placed under irrigation and natural salts (including nitrates and boron) in the soil root zone must be leached, with subsequent higher water tables in the presently irrigated lower lands. A drain is being constructed in order to carry the return flows to the ocean by way of San Francisco Bay. Because of already serious quality problems in the bay, this drainage water must be treated for nitrate removal before being released into the bay. One of the major difficulties is predicting the quantity of drainage water, as well as its quality. Thus, the magnitude of the potential problems can only be estimated at the present time.

The Yakima Valley in central Washington is an area which experiences considerable local difficulty due to irrigation return flow, but once the return flows reach the Columbia River, the quality degradation is minor because the Columbia River flow is many times larger than the Yakima River. Even so, there is a real need for an irrigation return flow control program because of competition from other uses (fishing, recreation, municipal, and industrial) within the Yakima River Basin, as well as to provide economic equity among the agricultural water users.

In addition to the problem areas cited above, there are numerous examples of irrigated areas in the West which experience water quality problems, many of them serious, due to irrigation return flow. Some examples are: the Pecos River in New Mexico and Texas; the Arkansas River Basin in Colorado, Kansas, Oklahoma, and Arkansas; the South Platte River in Colorado; the Platte River in Nebraska; the Sevier River in Utah; the Bear River in Utah and Idaho; the Humboldt River in Nevada; and the Santa Ana Basin in California. With the passing of time, the water quality problems in these areas will become more serious because of increasing water demands.

Although salinity problems due to irrigation return flow are not significant in much of the Pacific Northwest, water quality problems resulting from pesticides, nitrogen, phosphorus, nematodes, and sediments are very important. Also, there is considerable potential for increasing the irrigated acreage in the Columbia River Basin because of abundant water supplies. For example, Idaho could increase its irrigated cropland from 3.66 million acres (1969) to 8 million acres. Such an increase in irrigated acreage could be expected to have a dramatic effect upon the water quantity and quality of the Snake River.

Present-day technology is not sufficient for predicting the quality of irrigation return flow. Thus, there is a real problem in making long-range projections on water quality in a receiving stream due to irrigation projects. Consequently, the problems resulting from the development of new irrigation projects, particularly those involving lands not previously irrigated, are usually confronted after-the-fact.

The Navajo Indian Irrigation Project in northwestern New Mexico (Figure 3), which is presently under construction, will eventually irrigate 110,000 acres of land not previously irrigated. An initial block of 10,000 acres is scheduled for irrigation in the spring of 1975. Of the approximately 500,000 acre-feet of water to be diverted annually, half (250,000 acre-feet per year) of the water is expected to be return flow. There are estimates that the quality of these return flows will double in salt concentration due to evapotranspiration, but there are no estimates of salt pickup. Presently, the irrigation system for the initial block is being re-designed to provide more efficient water utilization. If this results in less water being diverted for the 110,000 acres, then the total salt load returning to the San Juan River will not be as great as would have occurred under the original plan of development due to reduced salt pickup. In any event, predicitons

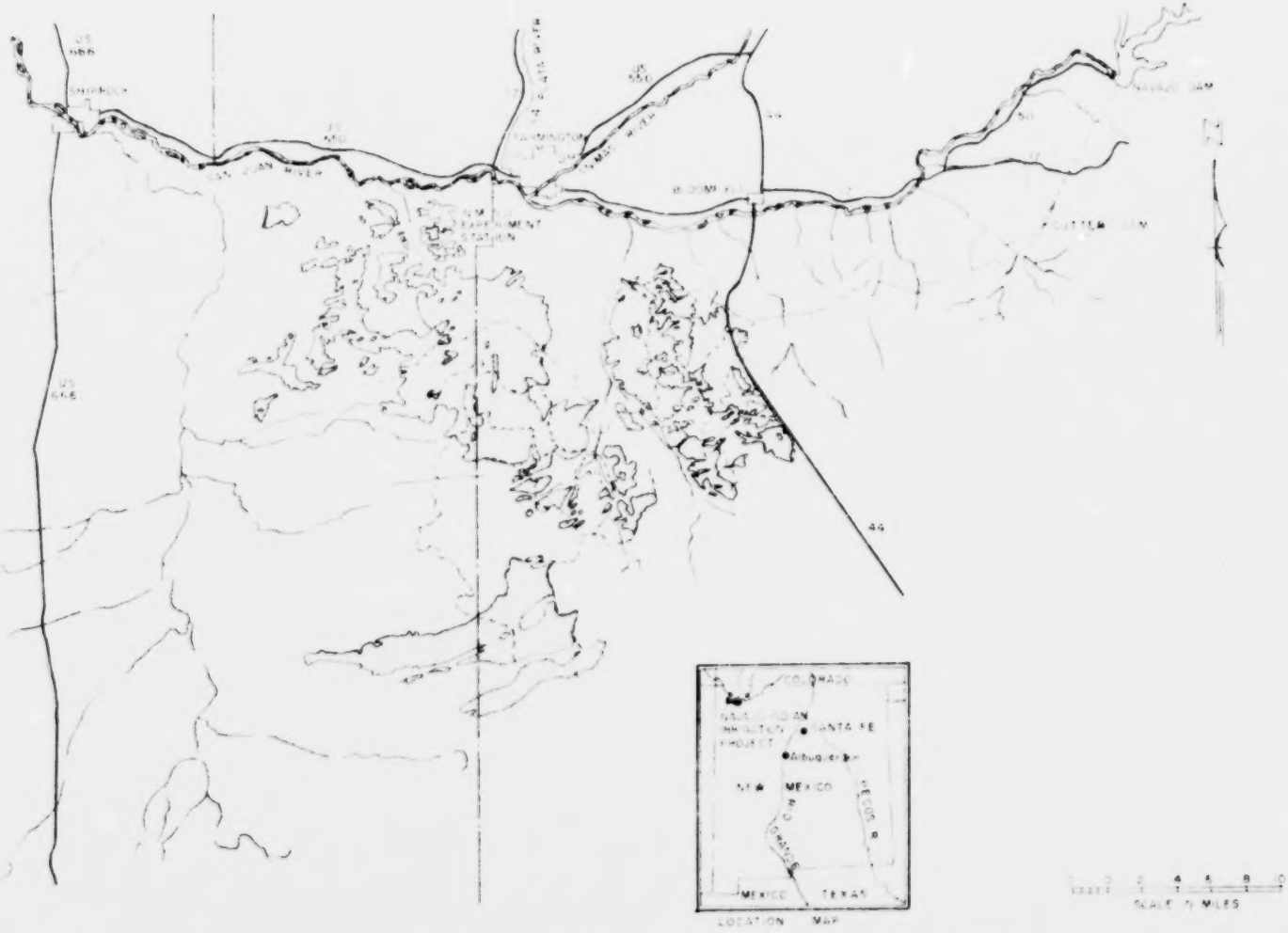

Figure 3 Navajo Indian Irrigation Project

of salt load returning to the San Juan River are not available. As a consequence, expected downstream damages in the Lower Colorado River to Arizona (particularly when the Central Arizona Project is constructed), California and Mexico are unknown with only very crude estimates being possible.

The Navajo Indian Irrigation Project is but one example of our present-day problems in predicting the effect of irrigation development upon the quality of downstream receiving waters. As our water resources become more fully utilized, the importance of irrigation return flow quality will be of even greater significance in the overall water management and development in a basin. If large-scale schemes for transporting water to the Intermountain West from the Columbia River Basin or Canada were to become a reality, what would be the effect of irrigating new desert lands in Utah and Nevada, or other adjacent areas? Questions similar to this can be raised regarding the effect of any projected changes to present water resource schemes. Intelligent answers are needed if we are to recommend and initiate control programs based on wise use of available technology. It is the intent and purpose of this report to point out those areas where present technology is lacking and indicate future courses toward technological development.

SECTION V

MAJOR WATER QUALITY PROBLEMS

Usually, the quality of water coming from the mountainous watersheds in the West is excellent. At the base of the mountain ranges, large quantities of water are diverted to valley croplands. Much of the diverted water is lost to the atmosphere by evapotranspiration (perhaps one-half to two-thirds of the diverted water), with the remaining water supply being irrigation return flow. This return flow will either be surface runoff, shallow horizontal subsurface flow, or will move vertically through the soil profile until it reaches a perched water table or the groundwater reservoir, where it will remain to be pumped or be transported through the groundwater reservoir until it reaches a river channel.

That portion of the water supply which has been diverted for irrigation but lost by evapotranspiration (consumed) is essentially salt-free. Therefore, the irrigation return flow will contain most of the salts originally in the water supply. The surface irrigation return flow will usually contain only slightly higher salt concentrations than the original water supply, but in some cases, the salinity may be increased significantly. Thus, the water percolating through the soil profile contains the majority of salt left behind by the water returned to the atmosphere as vapor through the phenomena of evaporation and transpiration. Consequently, the percolating soil water contains a higher concentration of salts. This is referred to as the "concentrating" effect.

As the water moves through the soil profile, it may pick up additional salts by dissolution. In addition, some salts may be precipitated in the soil, while there will be an exchange between some salt ions in the water and in the soil. The salts picked up by the water in addition to the salts which were in the water applied to the land are termed salt "pickup." The total salt load is the sum of the original mass of salt in the applied water as the result of the concentrating effect plus the salt pickup.

Whether irrigation return flows come from surface runoff or have returned to the system via the soil profile, the

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water can be expected to undergo a variety of quality changes due to varying exposure conditions. Drainage from surface sources consists mainly (there will be some precipitation runoff) of surface runoff from irrigated land. Because of its limited contact and exposure to the soil surface, the following changes in quality might be expected between application and runoff: (a) dissolved solids concentration only slightly increased; (b) addition of variable and fluctuating amounts of pesticides; (c) addition of variable amounts of fertilizer elements; (d) an increase in sediments and other colloidal material; (e) crop residues and other debris floated from the soil surface; and (f) increased bacterial content.

Drainage water that has moved through the soil profile will experience different changes in quality from surface runoff. Because of its more intimate contact with the soil and the dynamic soil-plant-water regime, the following changes in quality are predictable: (a) considerable increase in dissolved solids concentration; (b) the distribution of various cations and anions may be quite different; (c) variation in the total salt load depending on whether there has been deposition or leaching; (d) little or no sediment or colloidal material; (e) generally, increased nitrate content unless the applied water is unusually high in nitrates; (f) little or no phosphorus content; (g) general reduction of oxidizable organic substances; and (h) reduction of pathogenic organisms and coliform bacteria. Thus, either type of return flow will affect the receiving water in proportion to respective discharges and the relative quality of the receiving water.

The quality of irrigation water and return flow is determined largely by the amount and nature of the dissolved and suspended materials they contain. In natural waters, the materials are largely dissolved inorganic salts leached from rocks and minerals of the soils contacted by the water. Irrigation, municipal and industrial use and reuse of water concentrates these salts and adds additional kinds and amounts of pollutants. Many insecticides, fungicides, bactericides, herbicides, nematocides, as well as plant hormones, detergents, salts of heavy metals, and many organic compounds, render water less fit for irrigation and other beneficial uses.

Colorado River Basin

The variety of water quality problems resulting from irrigation return flow can be illustrated with a few examples. The major water quality problem in the western United States is

salinity, with the Colorado River Basin being one of the more serious problem areas. In addition to the problems caused by large quantities of good quality water being transported outside of the Basin, there is a tremendous problem due to salt pickup by the irrigation return flows passing through the soil profile and over saline shale beds before returning to the river. Also, there are a number of mineralized springs which further aggravate the salinity problem. The highest rates of salt pickup among the irrigated valleys within the basin occur in Grand Valley, Colorado and Castle Valley, Utah where the rate is about 8 tons of salt a year for each irrigated acre. Salt pickup rates of roughly 6 tons per acre per year result from irrigation in the Uncompahgre River Valley and Lower Gunnison River Valley, with both valleys being located in Colorado. High rates of salt pickup also occur at Big Sandy Creek Basin in Wyoming, Ashley Valley in Utah, and the Duchesne River Basin in Utah. Of the total salt load reaching Hoover Dam, the Environmental Protection Agency (12) estimates that 37 percent is the result of salt pickup from deep percolating irrigation return flows.

The Colorado River Board of California (8) has made predictions of future salinity at Parker Dam (diversion point for the Metropolitan Water District of Southern California) and Imperial Dam (diversion point for All-American Canal which serves Imperial and Coachella Valleys) based upon anticipated upstream water development (Figure 4). By the year 2000, the projected salinity levels at Parker Dam and Imperial Dam will be 1110 ppm and 1340 ppm, respectively, whereas the present levels are 740 ppm and 850 ppm. The estimated damages to California by the turn of the century could amount to $40 million per year (8). In addition, Arizona and the Republic of Mexico would also suffer severe damages.

Imperial and Coachella Valleys, Southern California. The high concentrations of salt in the water supply to Imperial Valley, combined with problems of tight soils and high summer temperatures, result in many difficulties for the farmer in growing a crop. The biggest problem is maintaining a salt balance in the root zone. A salt balance for the valley as a whole was first achieved in 1949. The option of using sprinkler irrigation is unavailable to the Imperial Valley farmer in many instances because the combination of salt and water deposited on a leaf in one rotation of the sprinkler has dried and left only the salt, with consequent toxic effects due to salt concentration and absorption, before the sprinkler can complete another rotation. Salt toxicity

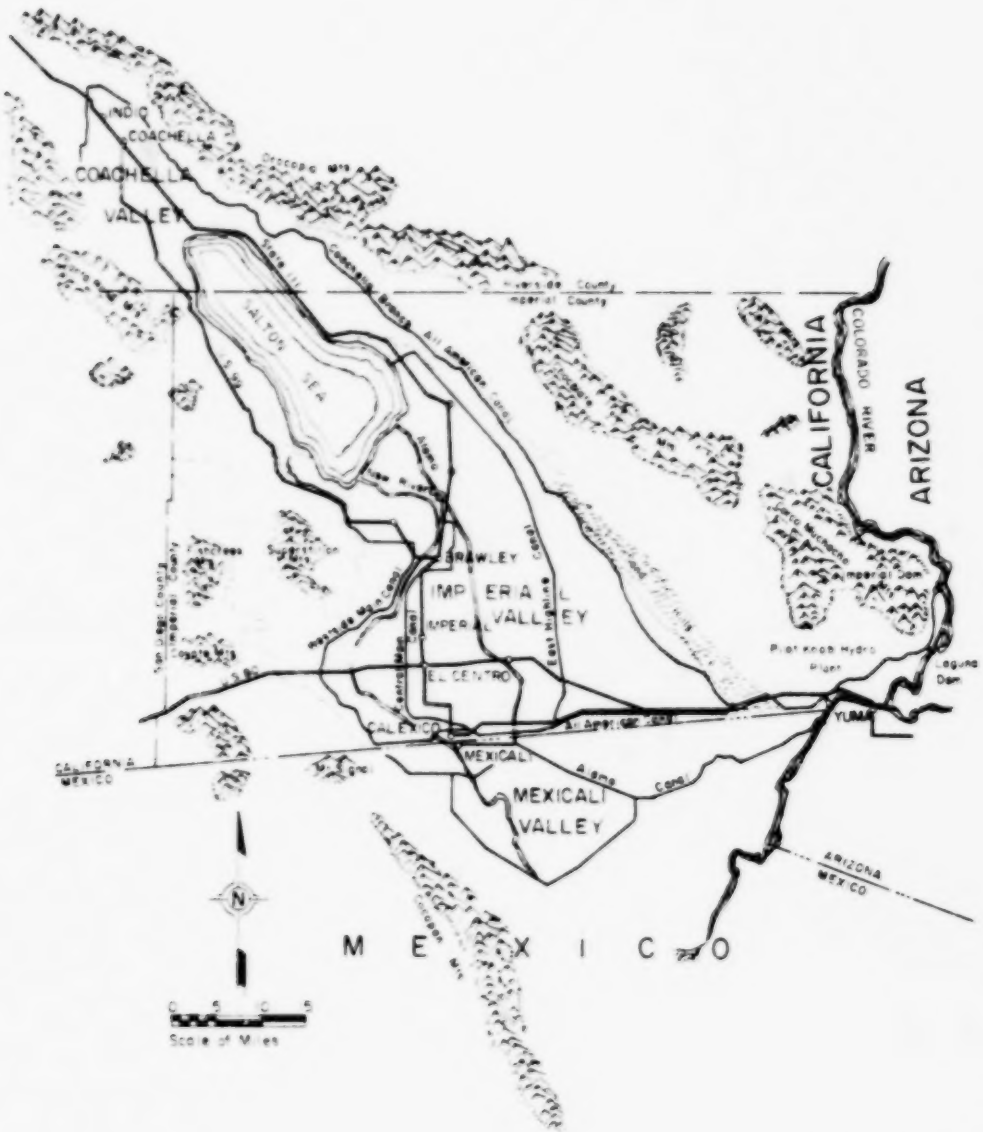

Figure 4 Coachella Valley, Salton Sea, Imperial Valley, and Mexicali Valley

results in the demise of plant foliage. Because of the tight soils, with consequent low infiltration rates, there is a real difficulty in getting enough water to pass through the root zone to assure that there is no salt accumulation in the root zone, which would result in lower crop yields. Cultural practices play a critical role in the infiltration of the irrigation water into the soil profile. Also, seed bed preparation is very critical. Changing the depth of seed placement one-half inch may result in the seed not germinating due to rapidly changing salinities in the soil solution with depth as a result of furrow irrigation.

An interesting cultural practice in the Imperial Valley is the use of sprinklers to germinate lettuce seeds. Oftimes salinity is high enough in the seed bed to inhibit germination. Portable sprinkler lines are set in place and adequate moisture added to leach salts and bring about uniform germination of the planted seed. Soon after seedlings emerge, sprinkling is discontinued, sprinkler lines are removed, and furrow irrigation resumed. This is a cultural practice that has been learned from experiments and is used to assure a uniform stand of lettuce, as an aid to harvesting.

The annual quantity of irrigation return flow from Imperial Valley is 900,000 acre-feet, while Coachella Valley returns 100,000 acre-feet. The return flows from these two areas are essentially the total inflow to the Salton Sea, which is approximately one million acre-feet per year. Of the total diverted to the valley, a minimum of 10-15 percent is required for leaching in order to maintain a favorable salt balance in the root zone. The leaching requirement of 10-15 percent would be satisfactory if equilibrium conditions existed. In practice, in order to gain on salt removal, a greater amount of leaching is required. The Imperial Irrigation District estimates the leaching requirement to be 20 percent to accomplish present levels of salt removal wherein the total annual quantity of salts removed is greater than the annual quantity of salts brought into the valley. Increasing salinity levels in the Colorado River will also increase the required leaching fraction. Based upon salt measurements of the inflow and outflow waters, calcium and magnesium carbonates and gypsum are being precipitated in the soil, while sodium and potassium chlorides are being removed from the soil. The precipitation and exchange of salt ions occur because the Colorado River water is high in calcium, bicarbonate, and sulfate. The necessity for maintaining a salt balance is somewhat alleviated by the high proportion of dissolved salt that is gypsum, which precipitates as an innocuous salt in the soil profile.

Salt balance studies have been reported for Coachella Valley, which is located on the north and west side of the Salton Sea, by Bower, Spencer, and Weeks (10). The 60,000 acres of irrigated land is served by the Coachella Branch of the All-American Canal, which diverts water from the Colorado River at Imperial Dam. Part of the Coachella Canal is concrete-lined and water diverted from the canal is transported in concrete pipelines to the individual farms, with the water being measured throughout the system. The delivery and use of large amounts of water from the Colorado River beginning in 1948 resulted in high groundwater levels developing in the valley. To alleviate this situation, tile drainage was installed. Presently, more than half of the lands have tile drainage. The studies showed that a salt balance (the annual tonnage of salts leaving the irrigated area, which enters the Salton Sea, is equal to or exceeds the annual tonnage of salts entering the valley from the Coachella Canal) was achieved when half of the irrigated land had tile drainage and the leaching fraction was 30 percent.

The irrigation return flow from Imperial Valley and Coachella Valley has a unique role related to water quality problems in the Salton Sea. At the time the Salton Sea was formed, in the period 1905 to 1907, it had essentially the same salinity as the Colorado River. Prior to this time, free salt was being mined in the area inundated by the Salton Sea. The present salinity of Salton Sea is approximately 40,000 ppm. At the time the salinity approached that of the ocean, the California Department of Fish and Game transplanted salt-water sport fish into the Salton Sea. For some time, these sport fish had difficulty surviving due to a lack of forage fish. Finally, a forage fish, the Corvino from Mexico, was found which would survive in the Salton Sea. Now, with salinities reaching higher levels than the ocean, it looks like much of this salt-water sport fishing will be lost. There is some talk of desalination. Eventually, the Salton Sea will assume many of the characteristics of Great Salt Lake. Reducing the quantity of irrigation return flow reaching the Salton Sea would only aggravate the present problems.

Wellton-Mohawk District, Arizona. Attempts to develop irrigation in the Wellton-Mohawk District of the Gila River Valley were unsuccessful until Colorado River water diversion was authorized by the Gila Project in 1947. The Gila River proved an undependable supply as upstream development progressed, and irrigation from wells failed as water levels declined and the groundwater quality deteriorated from

continual evapotranspiration and recirculation (39). Soon after the introduction of Colorado River water, the drainage problem became serious and was solved by the selective placement of wells to remove the poor quality groundwater. A concrete-lined channel was constructed to convey the poor quality drainage from the valley without creating further drainage and salinity problems in the lower lands. Although this was a more expensive scheme, it was justified on the basis of benefits derived from preventing further salt damages to productive lands. Further benefits were derived by conveying the saline drainage waters to the Colorado River downstream from Morelos Dam, the diversion point for irrigation water going into Mexico. If at some future time the quality of the Wellton-Mohawk drainage water improves sufficiently, it may again be used as a portion of Mexico's supply. Until that time, the Mexican water quality is being protected by having the saline drainage water bypass Morelos Dam. This is cited as an example of diversion away from a portion of a river system for the purpose of controlling the quality of the water resources in the basin. Another example of conveying drainage waters to a discharge point other than the river system is in the San Joaquin Valley of central California.

Rio Grande Basin

Salt balance studies have been conducted in the Rio Grande Basin for a number of years. The results of a 20-year study were reported by Wilcox (31) and are summarized in Table 7. Several diversions for irrigation occur along the Rio Grande between Otowi Bridge near Santa Fe, New Mexico and Fort Quitman, Texas below El Paso. The four main irrigated areas at the time of the study were as follows: (a) 80,000 acres between Otowi Bridge and San Marcial; (b) 15,000 acres between Caballo Dam and Leasburg Dam; (c) 70,000 acres between Leasburg Dam and El Paso; and (d) 85,000 acres between El Paso and Fort Quitman. A close correlation exists between the irrigated areas, decreased discharge, and increased salt load of the river. While the discharge is decreased to one-fifth its original value, the dissolved solids concentration is increased almost 10-fold and the total salt load is almost doubled. Although the salt balance appears favorable between all stations except El Paso and Fort Quitman, much more detailed information is required before positive statements regarding the salt status of the irrigated soils could be made. The overall effects have been almost totally attributed to the use of water for irrigation. The sources of salts returned to the river have not

Table 7. Mean annual discharge and dissolved solids, Rio Grande.[1/]

Station	Discharge 1,000 acre-ft	Dissolved Solids	
		ppm	1,000 tons
Otowi Bridge, N.M.	1,079	221	324
San Marcial, N.M.	853	449	520
Elephant Butte Outlet, N.M.	790	478	514
Caballo Dam, N.M.	781	515	547
Leasburg Dam, N.M.	743	551	557
El Paso, Texas	525	787	562
Fort Quitman, Texas	203	1,691	467

1/ Adapted from Wilcox (31).

been identified. The dangers of such generalized conclusions can readily be seen. More detailed investigations will be required in order to suggest suitable and adequate control measures.

The high salinities encountered in the Rio Grande have resulted in agricultural damages to El Paso Valley because the more salt-sensitive crops cannot be grown in this area. The Mesilla Valley, which is roughly 40 miles upstream, has a wider range of crops that can be grown because of better quality water. The Hudspeth Irrigation District, which is located below El Paso, has encountered serious problems due to high concentrations of sodium salts, which drastically affect crop production.

Long-term projections for El Paso show that municipal and industrial water needs will require all of the flows in the Rio Grande, but it is presently anticipated that a large amount of this future water demand will have to come from groundwater supplies. The problem is compounded by the rapid growth rate of Juarez, which is located across the river from El Paso in the Republic of Mexico. Degradation of groundwater quality due to irrigation return flows moving through the soil profile could result in additional treatment costs when such water supplies are used to satisfy municipal and industrial water requirements. At the same time, studies are needed to evaluate the role of irrigation return flows in recharging the groundwater basin.

Agricultural lands in the lower Rio Grande Basin experience some of the same cultural problems encountered in Imperial Valley, namely tight soils and poor quality water. Irrigation return flows are not subject to reuse except in drought years when farmers pump from the drainage canals to supplement their supply. Consequently, there has been no real concern for the quality of drainage waters. A large part of the irrigated area is tile-drained to control groundwater levels and about 80 percent of the drainage water from the Texas side does not return to the river, but drains directly eastward to the Gulf Coast. No information is available regarding the quantity of nitrates, phosphates, or pesticides being carried to the Gulf by this route. Drains from the Mexican side do return to the Rio Grande and are of very poor quality. This occurs below Falcon Reservoir which supplies irrigation water to both Texas and Mexico. Careful farm water management and special cultural practices are required in order to move salts below the root zone and insure a productive agriculture. The quality problems

requiring further study for possible control are those resulting from nutrient and pesticide transport to the drainageways and eventually into the Gulf of Mexico.

A recent study in the lower Rio Grande Valley of south Texas (7) has shown the need for institutional reform to promote efficient water resource utilization. The institutional influences that were shown to hinder improved water management practices were antiquated water rights doctrine and an unuaually large number (34) of water control and irrigation districts in a three-county area. The major recommendations for reform included: (1) negotiable water rights; (2) consolidation of water districts into one master district; and (3) rehabilitation of outdated delivery and drainage facilities. Similar reforms could well be recommended for many of the irrigated valleys of the western states.

Central Valley of California

Sacramento Valley. The Sacramento Valley represents quite a different problem with respect to irrigation return flows, as opposed to the San Joaquin Valley. The annual flow of the Sacramento River is somewhere between 14 and 18 million acre-feet per year. There are one million acres of irrigated land in the valley. The quality of the water supply is very good. The Sacramento River outflow provides dilution and flushing for the Delta area of the San Francisco Bay system. In order to maintain the quality of water within the Delta, the State does not want to allow further degradation of the Sacramento River, along with controlling waste discharges into the Delta. The California State Water Resources Control Board intends to maintain the quality of the Sacramento River.

The Sacramento Valley is a major rice producing area. Rice is planted by airplane, fertilized by airplane (phosphates are applied prior to planting on dry ground), and insecticides are applied by airplane. The major pollutants resulting from these practices are nitrates, phosphates, and pesticides.

One of the present problems concerning the Delta area of the Central Valley is that a portion of the water supply is being diverted by the State Water Project from the Sacramento River Basin to southern California. Limited drainage problems in Sacramento Valley are occurring because of increased irrigation provided by additional surface water supplies being used on the west side of the Valley. These surface water supplies are replacing the former pumped water

supplies in some areas. At the present time, there are approximately 50,000 acres which have high water tables resulting from excessive water application.

San Joaquin Valley. In contrast to the Sacramento Valley to the north, the San Joaquin Valley experiences considerably greater water quality degradation in its irrigation return flows. The valley contains about 8 million acres of irrigable land of which about half is presently irrigated and approximately half of that acreage has a potential drainage problem. This comprises about 40 percent of the irrigable land of the State, but, without water imports, has available only one-sixth of the State's water resources (Figure 5). Importation of water from the north resulting from the California State Water Project, the Federal Delta-Mendota Canal, and the San Luis Project has allowed vast new acreage to be placed under irrigation (23), particularly on the arid western side of the valley. The irrigation water applied is of good quality with a total salinity of less than 500-700 ppm. Due to the high concentration of natural salts and native nitrates in the soils, drainage from the area will have salinities as high as 20,000 ppm, which may be reduced to the 3,000 ppm range after 50 years of irrigation and its concomitant leaching of the soil profiles. This severe water quality degradation precludes the reuse of the drainage water and has forced the consideration of drainage canals to convey the irrigation return flows to the ocean via San Francisco Bay. Portions of a federally constructed San Luis Drain have already been completed but are not yet conveying drainage waters. Farm tile drainage systems, which are not extensively used at the present time, return either to the San Joaquin River or are pumped back into the canal delivery system.

A unique problem exists in the San Joaquin drainage waters due to the relatively high nitrate content. A few studies to date have indicated the major source in this area to be natural nitrates in the soils and to a lesser extent, applied fertilizers. The possibility of damage to San Francisco Bay by release of these nitrates prompted extensive studies into potential treatment measures that might be used for their removal. Algae stripping and biological denitrification methods have been shown to be feasible solutions. Other researchers, working with submerged tile drains, have achieved a smaller degree of success. The cost of treatment is still high and further studies will no doubt be conducted before a final decision on the treatment scheme to be used will be made. The economic and legal problems involved may very well turn out to be the major blocks to solving the problem. Economists have investigated the abilities of the irrigators to bear the costs of

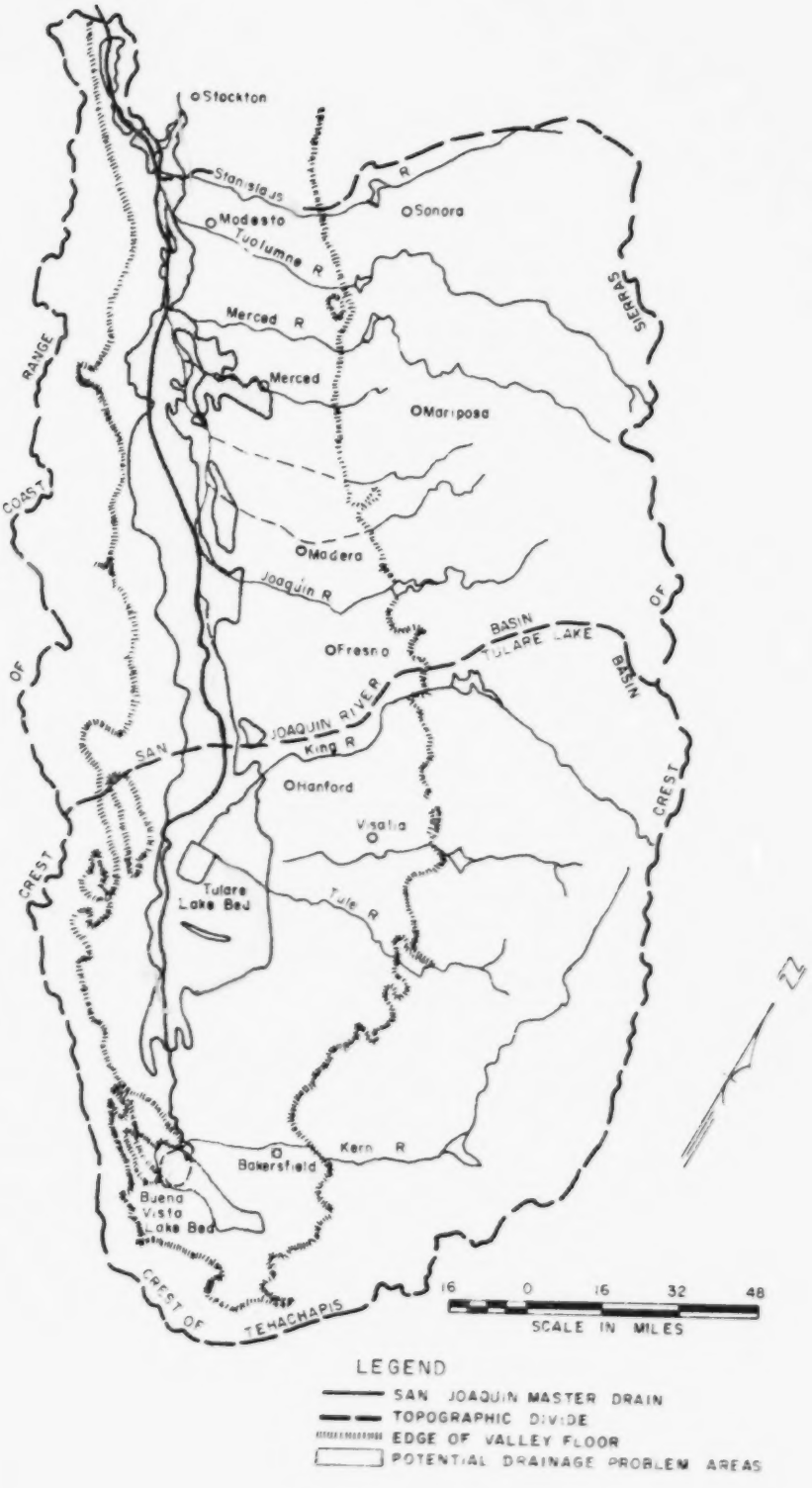

Figure 5. San Joaquin Valley

state-federal drains to convey irrigation return flows out of the valley. It is doubted that farmer acceptance of these added costs will be achieved until they are forced to do so. This still leaves the added cost of treatment to be considered and a further decision regarding proper and just allocation of those costs.

Under our present system, controlling practices on-the-farm is virtually impossible unless some means can be developed whereby there will be economic incentives for reducing water pollution. Extensive demonstration and education programs will be required to promote acceptance of improved farm management practices. This is true not only in the San Joaquin Valley, but in other critical problem areas as well. Control of leaching practices through improved water management in the newly irrigated fringes of the valley may be necessary to protect the lower lying lands from excessively saline groundwater seepage. Detailed salt mass balance studies will be required to evaluate the greatest long-term benefits and to protect those lands placed in jeopardy by the problem of increased salinity in drainage waters. These also are required to develop and recommend potential salinity control measures that could be most effective in protecting the quality of surface and groundwater resources. Some trade-off between the need for crop production and the need for reduced pollution may be necessary.

Columbia River Basin

The water quality problems resulting from irrigation return flow are extremely varied in the Columbia River Basin. Problems involving nitrates, phosphates, nematodes, sediments, and pesticides are prevalent in this region. Attempts to undertake solutions to these problems are important particularly since the problems will increase in complexity as the water supplies become more fully utilized.

Yakima Valley, Washington. One of the major areas of irrigation return flow quality problems is the Yakima Valley. There are presently approximately 400,000 acres of land under irrigation in the valley, with the potential for another 300,000 acres to be irrigated if the water supply were made available to some of the higher lands. An extensive irrigation return flow study in the Yakima River Basin (27) has shown the major water quality problems resulting from irrigation. The following discussion summarizes the findings of that study.

The Yakima River drains an area of 6,120 sq. mi., including over 400,000 acres of land irrigated for the production of a variety of crops (Figure 6). It has a mean annual flow of 3,900 cfs which is partially regulated by six reservoirs in the headwaters. Natural water quality variations occur with changes in the rate of runoff and reservoir releases. In the lower 80 miles of the valley, the summer flow of 1200 to 2000 cfs consists almost entirely of irrigation return flow, and during the irrigation season, the entire flow of the river is diverted several times for irrigation use. The study revealed that irrigation return flow was the major factor influencing the overall quality of the Yakima River and that leaching and subsurface drainage were responsible for the increased salinity and change in ionic composition of salts in the river. Thus, irrigation return flows were the major contributors to the 10-fold increase in dissolved solids, from 40-50 ppm in the headwaters to 400-500 ppm below the irrigated areas. Much worse water quality degradation results from sediment transport and nutrient releases to the river. Over-irrigation and fertilizer applications in excess of crop requirements were found to be the major causes of water quality degradation downstream. Increased turbidity (suspended solids) was particularly bothersome to downstream irrigators and one of the main reasons why sprinkler methods are not used more extensively. Improved water and fertilizer management practices were suggested as major factors in improving the quality of irrigation return flows in the entire valley area. The lack of adequate control over water delivery and water use results in over-irrigation. Although the water allotment is from three to three and one-half acre-feet per acre, the actual use was found to be as much as four to six acre-feet per acre per season.

Faulkner and Bolander (13) have investigated the transportation of nematodes in surface irrigation return flow, as well as the establishment of plant parasitic nematodes upon host plants. Their findings in Yakima Valley showed that plants irrigated with surface irrigation return flow became heavily infested with prarsitic nematodes. At the same time, plants irrigated with groundwater supplies did not become infested.

In summary, the major water quality problems occurring in the Yakima River Basin and other irrigated areas in the State of Washington are: sediment transport, nitrates, salinity (only in localized areas), nematodes, phosphorus on sediments, high bacterial (coliform) content in surface return flows, and increased temperature of surface return flows.

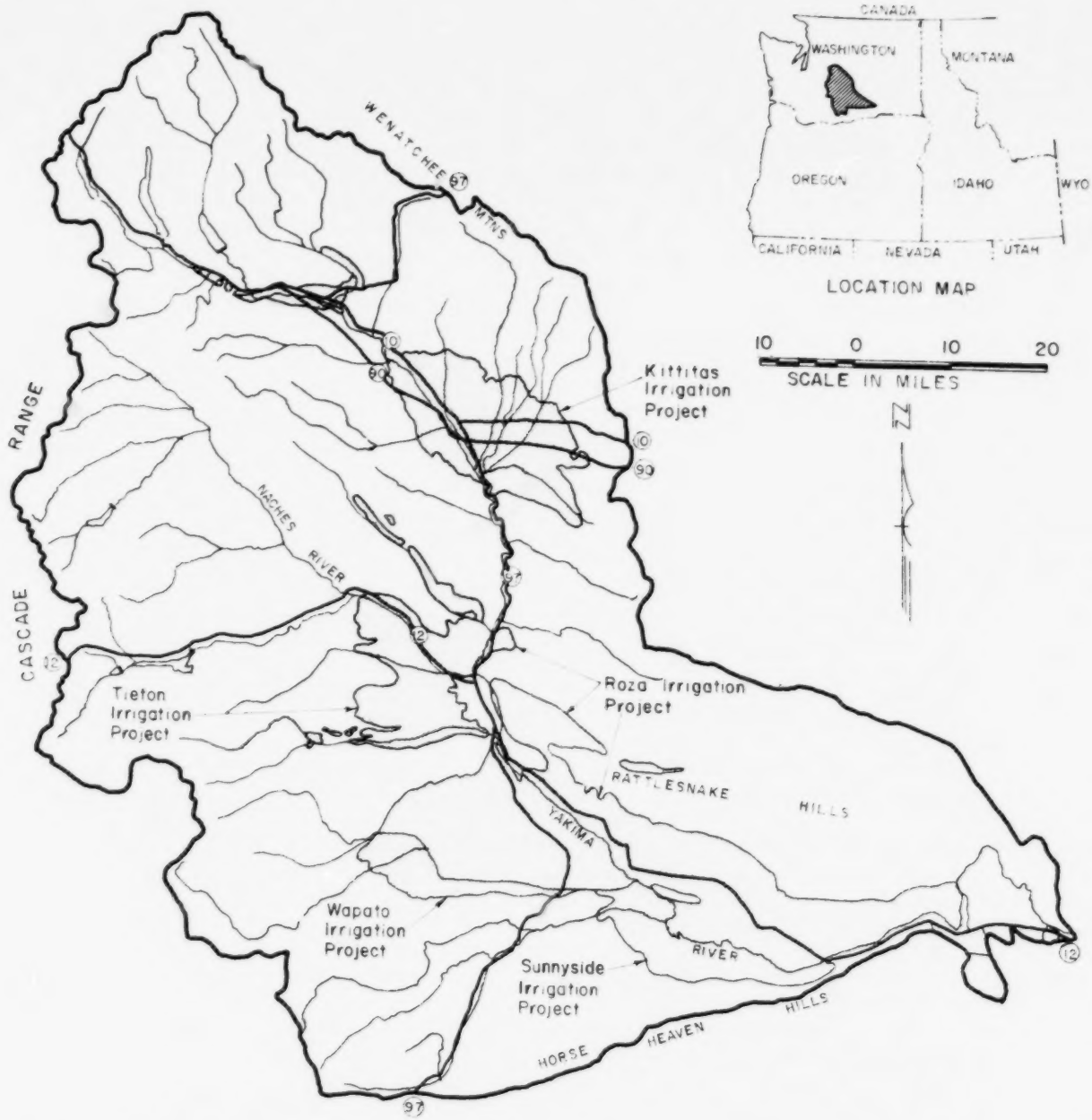

Figure 6 Irrigation development in the Yakima valley.

Snake River Valley. Irrigation return flows from the three million acres of irrigated land in the Snake River Basin present no really serious salinity problems. If the total potential of eight million irrigable acres were developed (Figure 7), water quality problems could develop. The chief reason for the quality of flow in the Snake River being maintained satisfactorily is that several large natural springs flow into the river downstream from the major irrigated areas. The Thousand Springs area below Twin Falls, Idaho contributes an average inflow of 4.3 million acre-feet per year. The quality of this inflow is very good (even better than Snake River water diverted above Twin Falls at Milner Dam) and results in a large dilution effect.

A recent sutdy (6) of the water-soluble nitrate, phosphate, and total salt balance on a large irrigation tract in the Twin Falls area is an excellent example of the type of investigations needed in many irrigation return flow problem areas. Typical information from such studies includes: quality and quantity of applied water, surface runoff, and subsurface drainage; fate of applied water; and the source of water quality problems from irrigation return flows. The major problems arising from this large tract were the nitrate-nitrogen contributed by subsurface drainage and sediment transport in surface return flows. The subsurface drainage water from the area contained lower total salt concentrations than irrigation water diverted at many locations in the Colorado and Rio Grande River basins. In areas not served by a canal system, some salt problems have developed from pumping groundwater with salt concentrations as high as 3,000 micro-mhos (electrical conductivity).

Examples of excessive water useage in areas of ample supply are the unusually high water duties allotted. In the Burley, Idaho area, the water duty (acre-feet of water diverted during the irrigation season for each acre of land) is approximately 6.5 acre-feet per acre per irrigation season; in the Rupert area, it is roughly 9 acre-feet per acre; and in the Rigby area of the upper Snake, the water duty goes as high as almost 13 acre-feet per acre. These are totally unrealistic when it is realized that crops (in Twin Falls tract, for example) require from 23 inches (spring grain) to 42 inches (irrigated pasture) estimated evapotranspiration for the entire year (6). In some rivers, the large quantities of seepage and deep percolation losses may benefit downstream water users because the return flows may coincide with periods of low streamflow and high water demands by crops. These problems fall within the realm of water management and serve to illustrate some of the antiquated institutional constraints in approaching optimum development of water resources. Although a number of

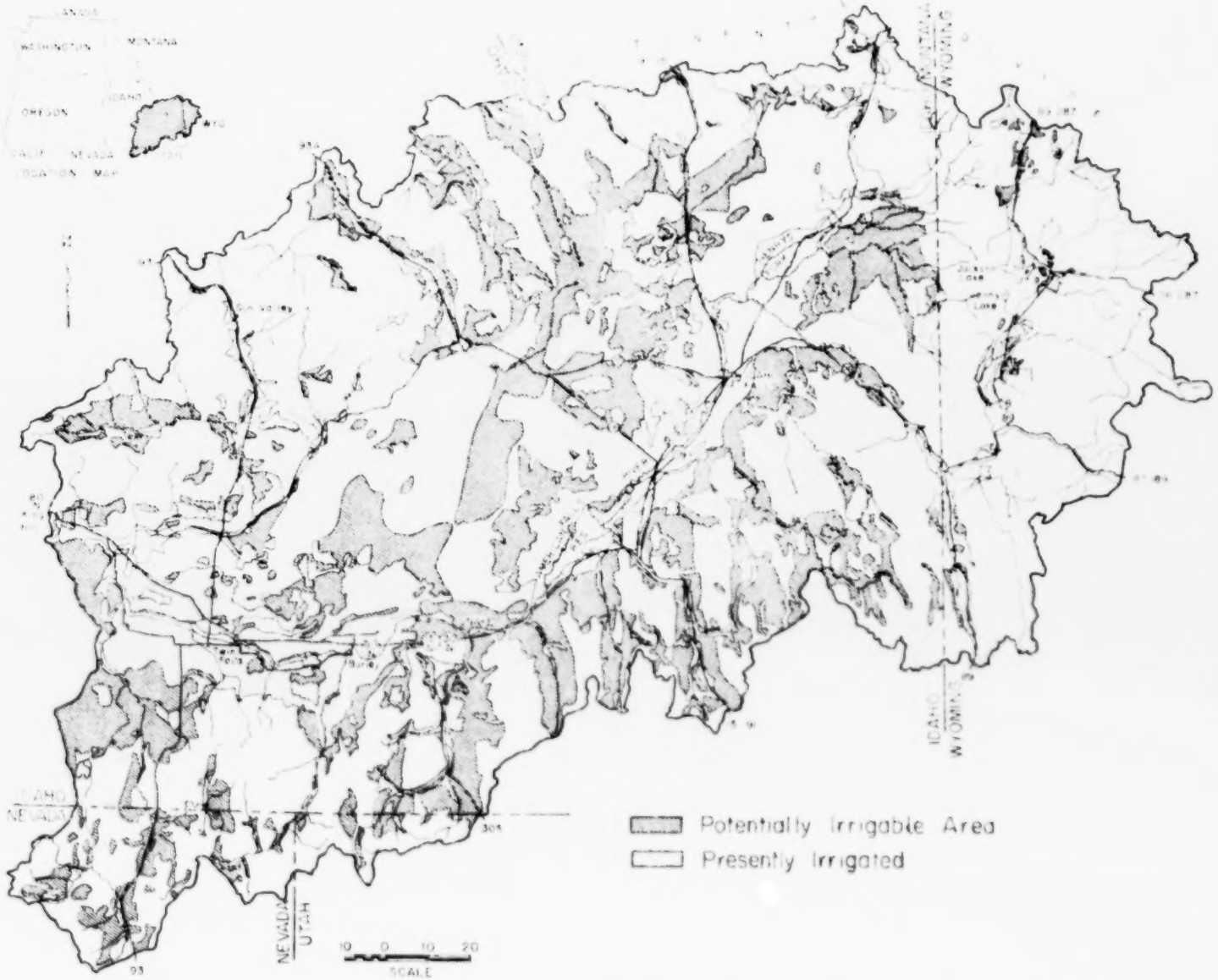

Figure 7 Presently Irrigated and Potentially Irrigable Areas in the Upper Snake River Basin

irrigated valleys having high water diversion rates do not presently create serious water quality problems, such practices become more critical as the water resources of the river basin become more fully utilized.

Some degree of management control is being achieved in southern Idaho through commercial concerns who sell a scientific irrigation scheduling service to the farmer. The potential for using this approach as a tool to limit quantity as well as time of application will be discussed more fully in the following section of this report (Section VI. Potential Solutions and Control Measures).

Odessa, Washington area. The Odessa area in the State of Washington has pumped domestic water from a shallow aquifer which occurs at depths of about 200 feet. Later, wells were drilled for purposes of supplying water to irrigated lands. These irrigation wells were drilled into deeper aquifers at depths of 400 to 700 feet below the ground surface. The return flows from the irrigated lands have now contaminated the shallow domestic wells. The drilling of irrigation wells began as a means of supplemental water supply for irrigation, but the area is now being more intensively irrigated and higher cash value crops are being grown. Also, the small lakes in the area are used for irrigation, but recreational potentials may be lost because of deteriorating water quality due to irrigation return flows.

The East High Project of the Columbia Basin, which would consist of approximately 500,000 acres of irrigated land, would also add to the problem in the Odessa area. The present problems in this area due to the development of groundwater supplies, and the consequent problem of irrigation return flows, would be considerably aggravated by the additional irrigation of 500,000 acres of new land.

Horse Heaven Hills, Washington. The Horse Heaven Hills area, which is located south of the Yakima River, has approximately 200,000 acres that could be easily placed under irrigation. Another 300,000 acres could be potentially placed under irrigation. The last 300,000 acres would create more of an irrigation return flow problem because this area consists of rolling hills and consequently would be faced with sediment erosion. These lands also contain over 6 million tons of leachable soil salts, which would be removed in drainage waters upon irrigation development. This is a typical problem for many of the agricultural lands in Washington which might be placed under irrigation in the future.

Lowe Columbia Basin. A significant problem in the sandy soil areas of the lower Columbia River Basin is the early season irrigation for wind erosion control. This sandy area encompasses roughly 100,000 to 200,000 acres. Sprinkler irrigation is used to apply 3-5 inches of water from the time of pre-plant until early leaf stage for potatoes and beets. Much of the fertilizer applied prior to planting is leached from the root zone before any significant plant growth occurs.

The problem of high nitrates in groundwater came into focus in the lower Columbia River Basin during 1962, when two cases of nitrate poisoning were reported. Subsequent analysis of well-water in this area by the U.S. Bureau of Reclamation disclosed that the water supplies from many wells contained nitrate concentrations ranging from 50 to 500 ppm. The source of this nitrate, whether it be from fertilizers or natural soil deposits, must be investigated before any recommendations on water or fertilizer practices can reasonably be initiated.

Santa Ana Basin, Southern California

The University of California, both at Riverside and Davis, has been deeply involved in studies in the Santa Ana River Basin. There are roughly 300,000 acres of irrigated land in the basin. The Santa Ana Water Planning Agency requested that a survey be made of nitrogen inputs in the valley, where the nitrogen is going, what nitrate problems exist, and recommend management practices to improve these problems.

The problems consist of water and fertilizer management on these irrigated lands, municipal-industrial wastewaters, as well as the disposal of animal wastes on the land.

With respect to fertilizer efficiency, there are some examples of vegetable crops in Santa Ana Basin where 300 to 400 pounds of nitrogen per crop per acre are needed but the application rate is more nearly 1,000 pounds of nitrogen per acre, with some cases as high as 1,700 pounds of nitrogen per acre. The higher usages of nitrogen are usually related to higher water usage as well. Thus, nitrogen efficiency can be related to water use efficiency, as well as management efficiency, with excessive water application leading to excessive leaching of plant nutrients before they can be utilized by the crop.

The basin is divided into two portions, an upper basin and a lower basin. This basin is divided by a natural dike almost at the county line (Orange County). Also, there is

a reservoir located near this dike. The groundwater table is fairly deep, but the salinity of this groundwater is increasing with time. The planning agency is very concerned about this increased salinity. It would be desirable to control the amount of salts and nitrates reaching the groundwater and, consequently, the amount of salts and nitrates reaching the reservoir at the county line. This reservoir has been the water supply for appreciable groundwater recharge in Orange County.

An informative area of different estimates by the planning agency and the university was the travel time of water moving from the ground surface down to the groundwater table. The planning agency developed map contours of travel time. These travel times were usually on the order of two or three years. In contrast, the university arrived at travel times in excess of ten years. This points out the difficulty in using existing data and rough estimates for arriving at travel time as opposed to making physical measurements in the soil in order to make an estimate.

Bear River, Utah

The headwaters of the Bear River are located in Utah. The river travels into the southwest portion of Wyoming, thence flows across southeastern Idaho and returns to northern Utah, where it terminates in the Great Salt Lake and is lost by evaporation. In the meantime, the flows have been diverted a number of times for irrigation. Flood irrigation is practiced on much of the upstream lands, with downstream users being dependent upon the return flow. Before reaching the Great Salt Lake, the flows of the Bear River pass through the Bear River Migratory Bird Refuge near Brigham City, Utah. The quality of the flows traveling through the refuge has been deteriorated due to irrigation return flow, surface water evaporation, and evapotranspiration by phreatophytes. The quality problem becomes serious during periods of low flow when most of the water is irrigation return flow. Although the irrigation return flow is essential, from a quantity standpoint, during periods of low flow, the poor quality of this water limits its usefulness.

Carson River, Nevada

The Carson River (Figure 8) has some similarities to the Bear River. The headwaters of the Carson River are in the Sierra Nevada Mountains. The flow is generally in an easterly direction. Large quantities of water are diverted at the base of the mountains to irrigate forage crops in

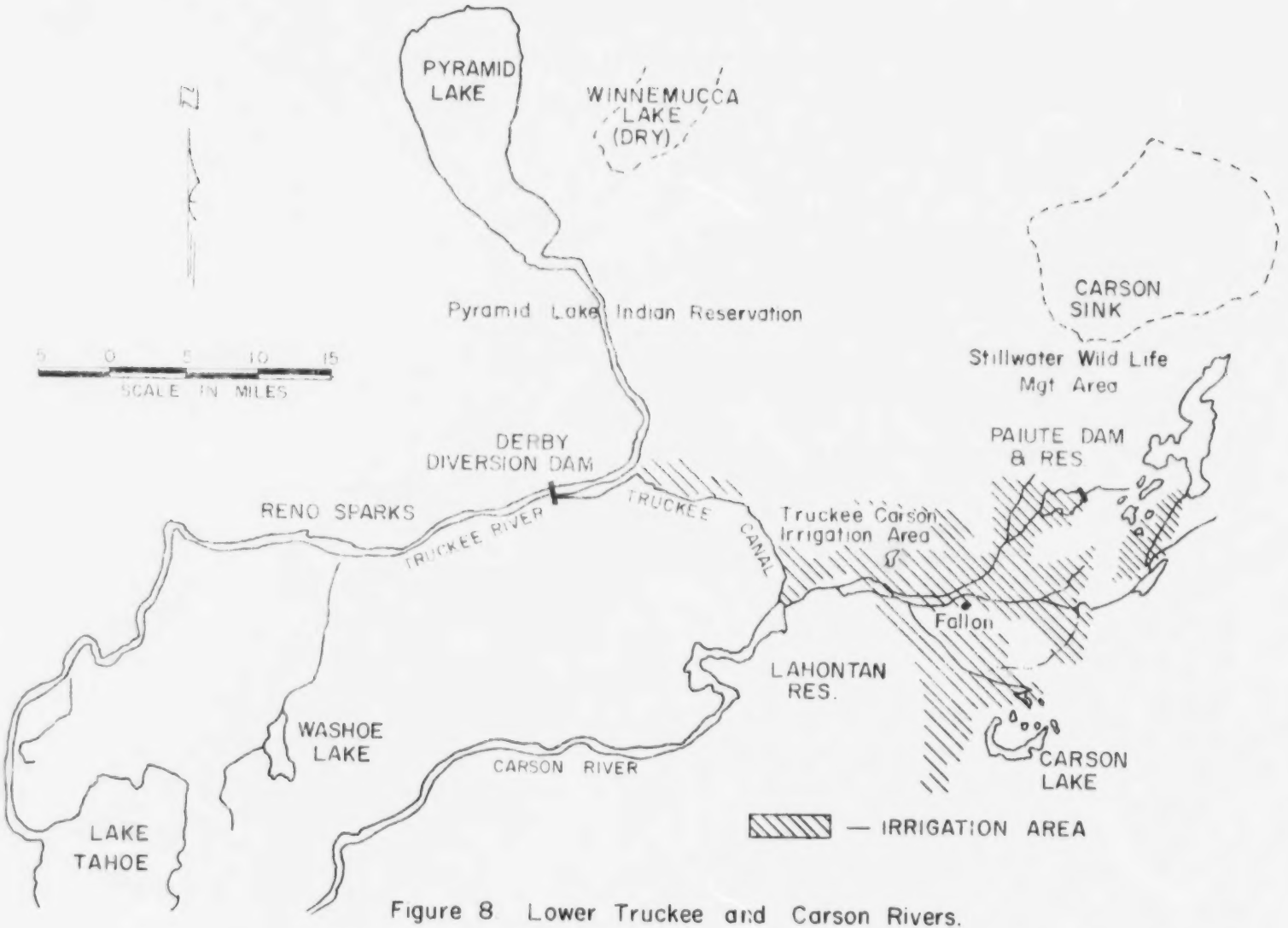

Figure 8 Lower Truckee and Carson Rivers.

Carson Valley. Eventually, the flows returning to the river are stored in Lahontan Reservoir, which is one of the earlier U.S. Bureau of Reclamation projects, just upstream from Fallon, Nevada. The stored waters are used to irrigate lands in the Fallon area, with the water duty (acre-feet of water diverted during the irrigation season for each acre of land) being very high. Consequently, the water table in the area is very near the surface and large populations of phreatophytes are supported (2).

The irrigation return flows are conveyed to the Carson Sinks, where the water is lost by evaporation. This sink area is managed as a waterfowl refuge. At the present time, quality problems in the refuge resulting from irrigation return flow are not as severe as encountered in the lower Bear River, but future water demands, as well as Indian water rights, can be expected to change this situation considerably. A balance will have to be reached between requirements for improved irrigation water management to release water supplies to satisfy Indian water rights, along with allowing a sufficient quantity of irrigation return flow having a satisfactory water quality to meet waterfowl needs in the refuge.

Upper Missouri River Basin

There are numerous examples of irrigation return flow quality problems throughout the Upper Missouri River Basin. Most of the quality problems that can be cited are the result of increased salinity, but this is largely due to a combination of two factors. First of all, the water supplies are fairly plentiful, which tends to mask quality degradation. Secondly, there is a real lack of documented studies regarding irrigation return flow quality in this region of the United States. The present knowledge on quality problems is the result of irrigation system failures or recent investigations undertaken for the purpose of expanding irrigated agriculture.

The State of Nebraska has plentiful water supplies and considerable potential for increasing its irrigated acreage. At the present time, more than 4 million acres of land are being irrigated in Nebraska. The present growth rate is approximately 250,000 acres of new irrigated land per year. Nebraska has 16 million acres of heavy soils amenable to surface irrigation and another 18 million acres of sand hills. At the same time, 8 million acre-feet of water per year is leaving the state. Thus, this water could be made available to new irrigated lands.

The water supply for much of the irrigated acreage in Nebraska is pumped from groundwater basins. Water reuse systems are

rapidly coming into existence in lower Nebraska (Lincoln to Hastings) because of groundwater pumping costs. The cost of a water reuse system has been estimated to be comparable to a pumping lift of 50 or 60 feet. Many farmers in this area are now pumping groundwater 100 feet.

Presently, the major irrigation return flow quality problem in Nebraska is the result of inefficient water use on a USBR project in the Tri-County area. The groundwater table has risen 100 feet in the last 20 years, until it is now near the ground surface, with resultant losses in agricultural productivity. The cost of surface water in this area is much lower than for pumping groundwater, which is at least part of the reason for the inefficient water use.

There are a number of examples of irrigation project failures, or near failures, in Wyoming. The Riverton Project has suffered from sodic conditions, which now make land reclamation economically unfeasible for many farms. Much of this problem could have been alleviated if canals had been lined, on-the-farm water management practices instituted, and drains constructed at the initiation of the project.

Areas in North Dakota and South Dakota, which are experiencing irrigation development, will face many salinity problems. Many of these lands are underlain by soils high in natural salts. Because of soils having low permeability, drainage will be required for many of these irrigation projects to insure their success. At the same time, irrigation return flow quality problems will increase substantially.

The Garrison Diversion Unit in North Dakota may be cited as an example. The plan for development involves the diversion of Missouri River water from Garrison Reservoir into the Red River of the North Basin to irrigate ultimately a total of one million acres. The lack of adequate prediction techniques precludes valid estimates of the impact of the irrigation return flows on the quality of Red River water. At the insistence of irrigators and water district personnel, the original plans were revised to include lined canals and pipeline distribution systems. Advantages of the revised plan include: adaptability to sprinkler methods and reduced land preparation costs; increased water control and water-use efficiencies; reduced weed control requirements; limited subsurface drainage needs; and lower operation and maintenance costs. No estimates of improved quality of return flows due to these revised plans (vs. original plan) were suggested, although some improvement would no doubt result. The need for prediction capabilities in newly irrigated areas is again emphasized.

Western Salinity Control Costs

Some informative estimates can be made based upon present-day knowledge and the projections for future land use (Table 3) and water use (Tables 5 and 6). Studies in the Twin Falls area (6) and the Colorado River Basin (8) indicate that the range of values for salt pickup from irrigated lands is roughly 1/2-8 tons per acre per year. An average salt pickup rate might be 2 tons per acre per year. Future water-use projections indicate a two-fold increase in irrigation efficiency by the year 2000. Consequently, a reasonable estimate for salt pickup reduction would be one-half, or 1 ton per acre per year. Using an estimated irrigated acreage at the turn of the century (year 2000) of 50 million acres for the western states, the annual reduction in salt load reaching our groundwater and surface water supplies would be 50 million tons per year.

Using the Colorado River Basin reconnaissance investigations as a guide, the total annual unit costs for achieving an annual salt load reduction of 50 million tons might be $20 per ton per year. Thus, the total annual costs would be 1 billion dollars, of which half, or more, could be attributed to salinity control, with the remaining costs being attributed to direct benefits for the irrigated croplands.

The benefits resulting from salinity control will increase dramatically with time. Projections for future water demands indicate many of the western river basins will be approaching full utilization of existing water supplies within the next 50 years. As these water supplies become more fully utilized, the necessity for salinity control, and consequently the benefits from salinity control measures, will increase exponentially. As a conservative estimate, the benefits should exceed the total costs by 50 percent. Also, the total costs for salinity control on an acre-foot basis are very minimal, being roughly $3-$10 per acre-foot per year for diverted water.

The above estimates are very crude due to a lack of better data. However, these estimates do provide "ballpark" values, which are advantageous in gaining an insight into the costs and benefits of salinity control. Other benefits such as reductions in sediments, phosphates, nitrates, and pesticides have not been taken into account, but would increase the benefits accruing from improved water management.

SECTION VI

POTENTIAL SOLUTIONS AND CONTROL MEASURES

Prevention or control of quality degradation to water resources due to irrigation return flow is both difficult and expensive to achieve. Potential solutions and control measures involve physical changes in the system, which can be brought about by constructing improvements to existing systems or by placing new institutional influences upon the system, or a combination of both. Since irrigation return flow is an integral part of the hydrologic system, control measures for managing the return flow from an irrigated area must be compatible with the objectives for water resource management and development in the total system. Irrigation return flow quality control is one component in the management of the water resources in a river basin, which has been long neglected. In many cases, environmental quality has been subjugated by economic pursuits.

The irrigation return flow system can be subdivided into three major sub-systems: (a) the water delivery system; (b) the farm; and (c) the water removal system. The water delivery system can be further subdivided into two components; namely, (a) the transport of water and pollutants from the headwaters of the watershed to the cross-section along the river where water is diverted to irrigate croplands, and (b) the transport of water and pollutants from the river diversion works to the individual farm. The farm sub-system begins at the point where water is delivered to the farm, which is usually the point of highest elevation on the farm, and continues to the point where surface water is removed from the farm, which is usually the lowest elevation ground surface on the farm. Also, the farm sub-system is defined vertically as beginning at the ground surface and terminating at the bottom of the root zone. The water removal sub-system consists of (a) the surface runoff from the tail end of the farm, and (b) water moving below the root zone.

In most instances, the quality problems in the water removal sub-system are minimized by having highly efficient water delivery and farm sub-systems. Minimizing the quantity of surface runoff will assist in alleviating quality problems due to sediments, phosphates, and

pesticides; whereas minimizing deep percolation losses from irrigated lands will reduce quality problems due to salts, including nitrates, in areas where salt pickup occurs.

Water Delivery System

The importation of high quality water from adjacent river basins, weather modification to increase precipitation and runoff from the watersheds, bypassing mineralized springs, evaporation reduction from water surfaces, and phreatophyte eradication are some of the available measures for improving the quality of water diverted from a river. Consequently, they play a role in the management of the irrigation return flow system. More feasible approaches may be found in the control of losses from storage and conveyance systems.

Canal and lateral lining. Many unlined irrigation canals traverse long distances between the diversion point and the farm land. Seepage losses may be considerable, resulting in low water conveyance efficiencies. Canal lining has traditionally been employed to prevent seepage and the economics of lining have been justified primarily on the basis of the value of the water saved. The possibility that water seeping from canals may greatly increase the total contribution of dissolved solids to receiving waters has only recently been given serious attention. A recent report (4) showed that average seasonal canal losses varied from 13 percent of the diversion on the Uncompahgre Project, Colorado, to 48 percent of the diversions on the Carlsbad Project, New Mexico. If we assume a very conservative estimate that 20% of the total water diverted for irrigation in the United States is lost by canal seepage, the loss to the intended users would be 24 million acre-feet per year. This quantity of water would irrigate eight million additional acres, using three acre-feet per acre, or it would contribute an additional dilution effect to the benefit of downstream users.

If soils along the canals are high in residual salts, the salt pickup contribution from this source could easily exceed that leached from the irrigated land to maintain a salt balance. The time required to leach these residual salts would depend upon the quantity of seepage and the quantity of salts. In addition to the quantity of water saved, the salt from this source could be largely eliminated by canal lining. The value of improved water quality is another benefit to be claimed in the economic justification of canal lining. Research is currently

underway to evaluate the effect of canal lining on the quality of drainage water returning to the river near Grand Junction, Colorado.

Evaporation losses from canals commonly amount to a few percent of the diverted water. The installation of a closed conduit (pipeline) conveyance system has the advantage of minimizing both seepage and evaporation losses. Either lined open channels or closed conduits will reduce evapotranspiration losses due to phreatophytes and other non-economic vegetation along canals. The closed conduit system uses less land and provides for better water control than a canal system. Water quality improvement may very well prove to be the greatest economic justification for closed conduit systems because of minimal seepage losses and considerable flexibility in water control.

Project efficiency. A key element that must be provided in the water delivery system is flow measurement. The amount of water passing key points in the irrigation delivery system must be known in order to provide water control and attain a high degree of water use efficiency. Many present day systems employ no flow measuring devices, and, in some cases, the individual farmer operates his own turnout facility with no close control of the amount diverted to the farm.

Economics play a major role in existing project irrigation efficiencies, and a close correlation exists between water abundance and/or cost of water and project efficiency. For example, where water is scarce or high in cost, the efficiencies are found to be higher. Project management, as well as farm management, involves balancing the immediate cost of water against the higher labor and investment costs required to use it more efficiently (17). The costs of inefficient water use oftimes are not recognized immediately but may be reflected in reduced yields due to nutrient losses or increased salinity, or in extra drainage facilities required later to control rising water tables.

On-the-Farm Water Management

The most significant improvements in controlling irrigation return flow quality will potentially come from improved on-the-farm water management. This will be particularly true for areas containing large quantities of natural pollutants, such as salts, in the soil profile. In such situations, the key is to minimize the subsurface return flows, thereby minimizing the quantity of pickup. Irrigation practices on the farm are the primary source of

present return flow quality problems. Besides improvements at the source, other improvements can be accomplished in the water removal system. Due to the nature of irrigated agriculture, whereby salts must be leached from the root zone, an optimum solution will, in most cases, require improvements in on-the-farm water management. Numerous technological and institutional concepts could be utilized to accomplish improved water quantity and quality management. Some of the technological possibilities are cited immediately below, whereas the institutional possibilities are discussed later in this section (Section VI).

Cultural practices. When the soils to be irrigated are tight (low infiltration rate and low permeability), and the water supply delivered to the farm is highly saline, cultural practices become extremely significant if crops are to be grown successfully. Under these conditions, the management alternatives become: (a) use more salt tolerant plants (which are usually lower in cash value); (b) use special soil tillage practices (which cost more); (c) leach in the off-season; (d) leach the field one year and plant a crop the next year; (e) prepare the seed-bed more carefully; or (f) control the timing and amount of water being applied. Usually, these problems must be faced in the lower regions of a river basin, where the accumulative effects of upstream water quality degradation, along with having finer soils resulting from river deposition, create difficult management conditions.

In general, the deeper water is stored in the soil, the more slowly it will be removed by evapotranspiration. Soil structure, texture and stratification are the principal properties that control distribution of water storage in the soil. In extreme cases, deep tillage may be required to disrupt slowly permeable layers and permit greater water storage capacity, as well as deeper root penetration. At the same time, excessive or unnecessary tillage can be detrimental to stored soil water, increasing evaporative losses when the crop needs it most. Therefore, cultural practices can play a significant role in overall farm water management.

Fertilizers. There is a strong relationship between water use efficiency and fertilizer use efficiency. Applying excessive quantities of water to the croplands results in leaching of fertilizer materials below the root zone, where they are unavailable for plant growth. One real potential for improving nitrogen use efficiency over some present management practices would be the use of slow-release fertilizers. There is still a need for improved technology for slow-release fertilizers to match nitrogen release with

nitrogen needs by various plants. At the present time, urea-based slow-release fertilizers cost about 40¢ per pound of nitrogen, whereas urea nitrogen costs approximately 10¢ a pound of nitrogen. Taking into account the efficiency of nitrogen use, the difference is only a factor of 2. Urea originally cost 30¢ to 40¢ per pound of nitrogen, but this cost dropped to 10¢ per pound of nitrogen as the volume used increased. If penalties for nitrogen discharge were imposed, slow-release fertilizers would be predominant in areas where nitrogen problems occurred. The use of slow-release fertilizers also has the advantage that by a proper match between nitrogen release and nitrogen needs by plants, only one fertilizer application would be required per season, rather than two, on vegetable crops. When applying fertilizer to crops which are not very salt tolerant, it then becomes necessary to limit the amount of fertilizer being applied. Another solution to this problem would be the application of fertilizer in small amounts with the irrigation water throughout the growing season, essentially spoon-feeding to meet crop requirements. Continual application of nitrogen fertilizer may impair ripening of certain crops.

Water control. In order to attain high irrigation application efficiencies, positive control of the timing and amount of water being delivered to the farm is required. The irrigator must also be able to control the water supply as it moves across the farm. The water delivery rate must be subject to regulation as well as the quantity applied at any given irrigation. Reducing seepage losses from farm ditches, preventing tailwater losses, improving water distribution over the field, and reducing unnecessary deep percolation losses are probably the most significant areas for improvement (24). Related to distribution system losses is water use by non-economic vegetation in or adjacent to farm ditches. Such plants not only extract water directly from the supply, but also from the soil under and adjacent to the ditch. This extraneous vegetation retards flow in the ditch and increases seepage and evaporative losses, and in extreme cases, may cause water waste by overflowing or breaking the ditchbank. Reduction of these losses is essential to water control on the farm.

Application methods. The effect of methods of application on the quality and quantity of return flow has not received detailed study. Conventional surface methods are most commonly used because of their low initial cost, while sprinkler methods are used because of their adaptability to a wide range of field and surface conditions and possibilities for reduced labor costs. In most areas,

there is a real need to "tune-up" the existing irrigation systems, thereby attaining the highest practicable irrigation application efficiency that can be achieved with these systems. New and unique approaches to application methods need to be found. Two that appear to offer promise in the control of both quantity and quality of return flows are subsurface application and drip or "trickle" methods.

With subsurface irrigation, water can be applied to the crop in small amounts and at frequent intervals so that evaporation and the resultant increase in salt concentration are reduced. The average water content of the soil can be maintained below field capacity (at points of moisture application, the water content is above field capacity), so that some precipitation can be stored in the soil. Comparable crop yields have been produced with as much as 40 to 50 percent less water than is required with furrow irrigation. Thus, limited water supplies can be extended or the acreage which can be irrigated with a given constant water supply can be nearly doubled. Application rates can be closely controlled and the method can be readily automated.

The drip irrigation technique has been developed in Israel and received enthusiastic interest among many researchers throughout the arid regions of the world. The major advantages include increased crop yield, reduced salinity damage, and shortened growing season with earlier harvest. The method involves the slow release of water on the surface near the base of the plants. Evaporation losses are greatly reduced and moisture release is confined to the area of the plant root system. Salts will accumulate in certain portions of the root zone during the growing season, which must eventually be leached. Some very different, but little understood, salt problems may result from this system.

Evapotranspiration control. Control of evaporation and/or transpiration offers another means of increasing irrigation efficiency and improving the quality of irrigation return flows. Such practices as mulching and reduced tillage can be highly advantageous in reducing soil water evaporation. Blevins, et al (3) demonstrated, with no-tillage studies on corn, a significant decrease in soil water evaporation and greater ability of the soil to store water for use by the crop. By conserving soil moisture, higher corn yields were produced. Surface mulching either with crop residues or artificial barriers has proven effective in reducing water vapor transfer to the atmosphere. Certain surface active agents also have been

shown beneficial in more rapidly establishing a dry barrier at the soil surface and thus reducing evaporative water loss (18). The irrigation methods described above (subsurface application and trickle irrigation) offer a great potential for reducing the nonbeneficial evaporative losses of irrigation water applied, thus increasing irrigation efficiencies.

Robins (24) provided an excellent review of the subject of evapotranspiration control as related to irrigation requirement. Attainment of any reduction of evapotranspiration, either beneficial or nonbeneficial, would reduce the quantity of irrigation water required for successful crop production. It has been estimated (1) that nonbeneficial use of water by phreatophytes and other water-loving plants amounts to 25 million acre-feet of water annually in the 17 western states. This amount obviously is lost from the potential for growing economic crops and represents a sizeable fraction of the total water resource. Reduction of this water use by any means possible represents a practical way to increase river flows and thereby reduce salt concentration.

Possibilities exist for reducing evapotranspiration of economic crops by altering climatic, soil, plant, and water management practices (24). Basically, evapotranspiration is an evaporative process controlled largely by the climatic factors, solar radiation, temperature, relative humidity, and wind velocity. Obviously, most of these would be difficult to control in large field areas. Three broad groups of antitranspirants that have been investigated are: (a) reflective materials that decrease the heat load on the leaf; (b) film-forming materials that hinder the escape of water vapor from the leaf; and (c) stomata-closing materials that increase stomatal resistance to water vapor transfer (10). Each of these types has been proven effective in reducing evapotranspiration, but as yet their use on a large scale has not been practiced. In addition to antitranspirants, substitution of cool season for warm season crops, and plant breeding and selection to achieve greater water use efficiency, have been suggested as potential control measures.

Optimum irrigation scheduling to extend the irrigation interval and apply water when needed and in the correct amount can exercise beneficial control over evapotranspiration, particularly during periods when crop cover is incomplete.

Pumpback system. One excellent technique for managing irrigation return flows would be the use of a pumpback system for tailwater control. Such a system would increase irrigation efficiency and minimize pesticides, phosphorus, and heavy metals returning to the return flow system. This would also serve as a self-policing system since the farmer would be more prone to be careful about harmful pollutants being placed on the land or in the water.

The pumpback system can be highly advantageous for controlling sediment. Rather than allowing the water and sediment from surface irrigation return flow to be transported to the next farm, or back to the river, the surface return flow may be collected and recirculated. A tailwater pit for collection and storage will also serve as a sediment trap, where much of the suspended material will be deposited. Thus, improved irrigation practices would likely result in order to minimize the quantity of water and sediment leaving the cropland. Enforceable regulations may be required to effectively control tailwater losses.

Irrigation scheduling. Early studies by Israelson in about 1930 and later studies during the 1950's and 1960's have shown that in most irrigated areas the amount of water applied and the timing of this water application are quite random. For example, oftimes when the farmer finds that his field is dry, he will irrigate, but the irrigation application may be more than is really needed by the crop. Thus a two-fold problem occurs where the plant has already been stressed because of the field being too dry, which means that the yield has already been reduced. The second problem is due to more water being applied than was really necessary. In extreme cases, this might even lead to a problem of reduced aeration of the soil.

One of the more interesting areas of water management control presently being explored is that of optimum irrigation scheduling. The purpose of irrigation scheduling is to advise a farmer when to irrigate and how much water should be used (15,16). Primarily, a farmer relies on visual indications of crop response to decide when to irrigate, or he may have to irrigate on a fixed water rotation system. Irrigation scheduling is geared towards taking soil moisture measurements, along with computing potential consumptive use for the crops being grown, to determine when to irrigate and the quantity of water to be applied. As an example, in the Twin Falls-Burley area of Idaho, there were no acres of land being studied for irrigation scheduling in 1969, whereas 10,000 acres were under irrigation scheduling in 1970, and 40,000 acres are under the irrigation scheduling program during 1971. It is anticipated

that this acreage will increase to at least 100,000 acres during 1972, and hopefully the acreage will include all of the area in a few years' time.

The reason this program has been successful is because the measurements are being made by irrigation district personnel or commercial firms, which are then supplying the needed information to the farmers. This has saved the farmer the effort of going out and making these same measurements himself and then having to make decisions regarding the timing and quantity of irrigation water to be applied. Because of the busy schedule of the farmer, and the difficulty he might have in the initial interpretation of the data, the problem of irrigation scheduling has had little success in the past. The efforts in this area are extremely promising and the farmers are claiming a significant benefit from irrigation scheduling. Yields have been increased due to the fact that water was applied when needed rather than after the crops were stressed. In most cases to date, there has been very little reduction in water use, although it would seem likely that a decrease in water use would occur with time as the farmer gains more knowledge of what is actually occurring in the soil profile. Another benefit to the farmer from this program is that he can anticipate the dates when irrigation is to be accomplished. This allows him to schedule irrigations along with the other duties that must be performed on the farm and relieves him of the responsibility of deciding exactly when is the best time to irrigate.

Water Removal System

The water removal sub-system consists of removing surface runoff from agricultural lands (if not captured and pumped back on the farm) and receiving deep percolation losses from irrigation. The surface runoff, or tailwater, from one farm may become all or part of the water supply for an adjacent farm, may flow back into the water delivery system at some downstream location, or may be transported back to the river via an open drain, either natural or man-made. Before surface return flows reach the receiving stream, there are essentially three alternatives for preventing or minimizing the quantity of pollutants discharged into the river. A bypass channel could be constructed to some location where the flows could be discharged without returning to the river. A second alternative would be to store the return flows in shallow storage reservoirs and allow the water to evaporate, leaving behind the pollutants. Seepage must be controlled in bypass channels or storage reservoirs; otherwise the

groundwater may become contaminated. This second alternative has the disadvantage that pollutants are being collected, rather than discharged to the ocean, which may eventually create a real disposal problem.

The third alternative for minimizing the quality degradation in the receiving stream due to surface irrigation return flow would be to treat the return flow. Desalination processes could be used to restore the water supply to a desired quality level, but methods for disposing of brine wastes must be considered. If the problem is to remove nitrates, then the results of the research program at Firebaugh, California conducted by the Environmental Protection Agency, U.S. Bureau of Reclamation, and California Dept. of Water Resources could be used. In these studies, both algae stripping and bacterial denitrification proved to be the least costly nitrate removal methods.

Drainage and salinity control. Waterlogging and salinity pose a serious threat to many irrigated areas. Any expansion upslope from existing irrigated lands becomes a direct threat to the waterlogging of downslope areas [illegible]. For example, many of the fertile lands in the San Joaquin Valley of California are now threatened by upslope irrigation development, and some areas in the Yuma Valley of Arizona have been rendered unproductive by irrigation development on the Yuma Mesa. Equally dangerous threats exist from the salt balance problem of these areas. Recirculation of water by pumping or reuse of return flows results in a buildup of salinity. Concomitant with increased salinity are corresponding increases in the leaching requirement and drainage needs. Irrigation development, including impoundment, conveyance, and application, upsets the natural hydrologic cycle of an area. Recognition and solution of drainage and salinity problems in such areas requires an intensive application of control measures based on sound scientific knowledge.

For deep percolation losses, there are a few possibilities for managing the effect of water quality degradation upon receiving streams. In certain special situations, an impermeable barrier placed a short distance below the root zone would be effective in preventing moisture movement deeper into the soil profile or subsurface strata which might contain large amounts of natural salts. Thus, the deep percolation losses could be collected and diverted to the surface water removal system without being unnecessarily degraded by subsurface salinity.

Tile drainage is a very effective means for removing the less saline waters in the upper portions of the groundwater

reservoir, thereby reducing the mass of salts returning to the river. By using tile drainage, salts are allowed to accumulate below the drains. This is particularly true for soils high in natural salts. Tile drainage will not completely remove all of the water moving below the root zone unless the water table is lowered below the natural groundwater outlet. Usually, some water will still move through the groundwater reservoir and return to the surface river, but the quantity of such groundwater return flows can be reduced considerably by tile drainage. The quality degradation to receiving streams from tile drainage outflow can be minimized by treating the outflow. This points out another advantage of tile drainage. Tile drains allow the collection of subsurface return flows into a master drainage system for ease of control and treatment.

Institutional Influences

Irrigation return flow quality is largely a problem of economic "externalities." The harmful deeds of one farmer generally occur as a cost to someone else who may be located a considerable distance from the source of the problem. Conversely, the costs to one farmer for "cleaning up" his return flow will accrue as benefits to downstream water users. Thus, until the costs and benefits for an entire system are internalized, there is no real incentive for the upstream polluter to make investments for enhancing water quality. Economics are important in this problem area, but new legal and institutional frameworks must be created to effectively deal with the problem.

One of the most dramatic courses of action that could be taken to prevent quality degradation from irrigation return flow would be to eliminate irrigation from areas where high salt pickup rates occur, such as soils that are formed from shales, or are themselves high in natural salts. This concept may be more useful in preventing the development of new irrigated areas, rather than eliminating existing irrigated areas. Regulations may be required regarding the management of phosphate fertilizers (for areas having large quantities of surface runoff) or nitrogen fertilizers, or both. In some areas a regulation requiring the use of slow-release fertilizers may be necessary.

Tailwater control would be advantageous for controlling sediment. Sediment is also a problem because of plugging of sprinkler nozzles in sprinkler irrigation systems. Besides controlling the transport of pollutants, there are other environmental considerations, such as mosquito

abatement. Each farmer would be required to control tailwater, or surface runoff, by means of lagoons or some pumping system. A regulation could be put into effect that would not allow surface runoff to leave the farm. A permit system might be used to enforce this regulation. A farmer might be able to have surface runoff, provided the next farmer below him would be willing to accept such surface runoff. This would overcome the problem where some farmer's water supply is dependent upon return flows from the farmer above. This would also relieve the problem in areas where large amounts of water are flooded over the land and the next lower farmer receives the surface runoff from this flooding. To change such a system would require extensive physical changes in the delivery and farm irrigation systems, but such costs would frequently be comparable to costs of other control measures.

There is a possibility that a schedule of money charges could be applied for excessive water use. For example, if the determination had been made as to the amount of water really required for a crop, then this amount of water could be delivered to the farmer for the reasonable charge of operation-maintenance costs. If any additional water were to be used by the farmer, which would only be possible if he had previously developed a water right for such water, then there would be a higher charge for the additional amount of water beyond that required by the crop. This might work in such a way that for the first 15% of water beyond the crop need would be charged at perhaps double the rate of water for that needed by the crops, whereas the next 15% might be quadruple the cost of water needed for the crop, etc.

There must be some economic incentive for an irrigator to control irrigation return flow. Such incentives can be negative or positive. For example, a regulation disallowing tailwater runoff costs the farmer additional money without any apparent economic return, thereby becoming a negative economic incentive. Now if this same farmer could be shown that preventing tailwater runoff would reduce the amount of water needed, reduce erosion, increase crop yields, and increase the efficiency of fertilizer use, and such benefits were greater than his additional operating costs in preventing tailwater runoff, then he has a positive economic incentive. Educational programs could be highly beneficial in promoting irrigation return flow quality control, especially if a positive economic incentive can be shown. Showing economic gain to the water user often requires field demonstration projects that can be seen, rather than facts and figures developed from a paper (desk) study.

Our western water laws contribute substantially to the irrigation return flow quality problems. There is no incentive to conserve water as most of the irrigated valleys in the West. Everyone feels they must use their full water right for fear of losing any portion of the unused right. Although such attitudes frequently contribute to local water logging problems, the practice persists. Usually, the disadvantages from this practice are passed on to downstream water users. In Colorado, for example, a farmer having an adequate water right, who lines his farm ditches or otherwise conserves water, cannot use the saved water to irrigate additional land or as a supplemental water supply for lands having an inadequate water right. If the same farmer has an inadequate water right for his land and used water conservation measures to allow more water to become available to his land, he benefits from the improvements and has not jeopardized his water right. Thus, a farmer having an adequate water right has no, or very little, economic incentive for improving his water management. This clearly points out the necessity for changing our present institutions.

Our basic water laws are probably satisfactory, but the interpretation of these laws must be changed to encourage more efficient water use. A water bank is needed where water could be bought or sold. For example, if each farmer could obtain some monetary benefit by conserving water, then a positive economic incentive would exist. The water saved by one farmer could be rented to a farmer having an inadequate water supply. This way, the water supply could be reallocated within the irrigated valley to meet the consumptive water demands quite efficiently. In most irrigated valleys, there are problems of maldistribution of the water supply. At the same time, there could be a net water surplus. Thus, net water savings could be sold or rented to satisfy other water demands. To accomplish such water exchanges would require some safeguards that the transfer was desirable from the standpoint of fitting into a comprehensive river resources development plan for the basin. Also, there would have to be some legal safeguard to protect third parties' rights. This could be accomplished by allowing the right of condemnation in such affairs. Such a water bank would provide economic recognition for the value of conserved water.

Irrigation scheduling is probably the most universally known practice for improving water management and increasing crop production. This technique is applicable to irrigation practices but the economic benefits do not overcome the negative aspects of western water laws. Also, the irrigation

scheduling reported to date does not cite any reduction in total water use, this reduction will take place as more experience is gained by the farmer regarding soil moisture management in the root zone of his croplands. Even so, the farmer may still wish to divert his full water right. Again, if the farmer could receive an economic return by being allowed to transfer the saved water, then the improvements in irrigation water use efficiency could be brought about at a much faster pace.

Only a few of the irrigated valleys are operated as a single management unit. In many valleys, several irrigation companies exist, with each company responsible for water delivery to a portion of the valley. In many cases, separate institutions exist to handle the water removal (drainage system). Numerous examples could be cited where 20-30 irrigation companies operate in a single valley. In order to develop effective irrigation return flow quality control programs, the quality degradation resulting from the entire irrigated valley must be ascertained. Then alternatives for controlling irrigation return flow must be developed, which will be primarily valley-wide alternatives. Thus, there is a real need to work with a group representing the agricultural interests of the entire valley. The consolidation of the separate irrigation companies into a single entity would have many advantages to local interests in improving agricultural development in the area, as well as providing a single entity for more effectively bringing about improved water management programs to reduce quality degradation in receiving streams due to irrigation return flow.

One concept that could be used in order to manage the irrigation return flow problem would be to require the one degrading the quality of water to pay the cost of treating this water. This concept might be applied on an individual farm basis. Having the individual farmer take care of his own problems might become extremely difficult (if not impossible, or nearly so) for deep percolation losses. Thus, there would be a need for a large district to handle the costs of treating the return flows. This would require that all return flows be collected at some downstream point where they would then be amenable to treatment. The degree of required treatment should differentiate between the pollutants already present in the applied water as compared with the pollutants added due to irrigated agriculture. The costs would then be distributed back to the individual farmers. Such a measure would have the advantage of placing greater stress on

water management in order to minimize deep percolation losses and the associated costs of collection and treatment.

An example of having irrigation return flows treated would be the San Joaquin Master Drain. The costs for this treatment could be distributed back to the farmers, but economically, it could be shown that everyone in the basin gathers some benefits due to this drain. Thus, there should possibly be a payment by everyone within the basin for the drain. This is a real question of economic benefits. The problem becomes one of defining these benefits and distributing the costs.

There are a number of economic questions that could be asked regarding the distribution of costs and benefits resulting from irrigation return flow. For example, in the Santa Ana Basin, who should pay the costs of treating the contaminated groundwater supplies? If a canal is lined to reduce seepage losses and consequent salt pickup, how should the costs be distributed among local water users, downstream water users, and the public, either locally, regionally, or nationally?

One real means for improving irrigation return flow quality, which has been pointed out a number of times, is to improve the efficiency of water use on the farm, but taking into account the leaching requirement for maintaining a salt balance in the root zone. One of the problems that makes this difficult is that certain farmers are more able to return capital investment to the farm for such operations as land leveling, ditch lining, or improved irrigation methods, whereas the marginal farmer is not able to return capital for farm improvements and thus usually has poorer efficiency. In looking at any incentive programs for improving irrigation return flow quality, it should be taken into account that some means must be provided whereby the marginal farmer could benefit by improved water management practices and consequent alleviation of water quality problems. When such investments are made, the marginal farmer probably benefits more than other farmers. For farmers with capital, there is still a problem if the return for such capital investments is lower than for alternative uses of capital.

In looking at the many alternatives for controlling irrigation return flow quality, it becomes evident that some of the conservation measures advocated over the past few decades have resulted in water quality improvements. For example, such practices as soil erosion control, canal and farm ditch lining, improved irrigation practices, and tile drainage

...ve water quality benefits. Therefore, many of these ...ctices should continue to be emphasized through educa... ...nal and action programs.

... Control Programs

As ...ded to previously, an irrigation return flow quality control program is only one component in the overall water resource planning and development of a river basin. Thus, any control program must fit into the long-range objectives for the basin. This also points out that the planning for a control program should be accomplished on a river basin basis. To date, the only control program which has been planned on a basin-wide scale is the proposed salinity control program for the Colorado River Basin. To illustrate a control program, the following material has been taken from the report, "Need for Controlling Salinity of the Colorado River," which was published by the Colorado River Board of California in August, 1970 (8).

Colorado River Basin. There are a number of sources of salinity throughout the Colorado River Basin that could be controlled by individual projects. The Environmental Protection Agency has identified a number of specific projects and has conducted limited reconnaissance level investigations. The Bureau of Reclamation has completed reconaissance level studies for one project. The Type I, Comprehensive Framework Studies for the Upper Colorado Region have also identified these projects in its reports (as yet unpublished). Salinity sources include twelve irrigated areas and five natural sources. Five flowing wells that together contributed 100,000 tons of salt annually to the river have already been plugged. The mean annual tonnage of salts reaching Hoover Dam is roughly 8 million. The cumulative effect of these projects would accomplish a substantial reduction in the river's salt load. It should be emphasized that these identified projects are not considered to be the only feasible projects, and that other, now unidentified, projects may also prove to be feasible (8).

Salt sources subject to control are located on Figure 9, "Proposed Salinity Control Projects." Average annual costs, including capital, operation and maintenance costs, are summarized in Table 8.

The twelve irrigated areas vary in size from 100,000 acres in Uncompahgre Valley, Colorado to several small irrigated

Figure 9. Proposed salinity control projects in the Colorado River Basin

Table 8. Estimated costs of salinity control projects (8).

Project	Salt Removed (Thousands Tons/Yr)	Annual Project Costs [a] (Thousands Dollars)	Unit Cost [b] (Dollars/ Ton/Yr)
Irrigation Improvements [c]			
Grand Valley	310	3,100	5.00
Lower Gunnison River	330	3,600	5.40
Price River	90	1,000	5.70
Uncompahgre River	320	4,000	6.30
Big Sandy Creek	40	490	6.30
Roaring Fork River	50	880	8.50
Upper Colorado River	80	1,400	8.90
Henrys Fork River	40	710	8.90
Dirty Devil River	40	710	8.90
Duchesne River	270	5,700	10.40
San Rafael River	70	1,400	10.50
Ashley Creek	40	800	11.60
Subtotal	1,680	23,790	
Stream Diversion			
Paradox Valley	180	700	3.90
Impoundment and Evaporation			
La Verkin Springs	80	600	7.50
Desalination			
Glenwood and Dotsero Springs	370	5,000	13.50
Blue Springs	500	16,000	32.00
Totals	2,810	46,100	
Weighted Average Unit Cost			12.30

[a] Annual project costs include amortized construction, operation and maintenance costs.

[b] The unit costs only include costs allocated to salinity control.

[c] Annual project costs for irrigation improvements incorporate all costs, including those allocated to the irrigation function. Costs allocated to salinity control projects were estimated to be one-half of total annual project costs.

areas in Utah and Wyoming. Measures to be used for salinity control would include lining canals, constructing drains, and improving irrigation efficiencies through modification of irrigation practices. These measures would reduce return flows and thereby decrease the quantity of water coming into contact with highly saline groundwater and underlying material. The degree of salt load reduction will vary from one area to another. Therefore, a detailed investigation is required for each irrigated valley in order to establish the amount of salt reduction which will result from each water management alternative. Also, the costs and benefits must be established for each alternative. Based on studies conducted by the Environmental Protection Agency (12), it was estimated that the combination of these control measures would reduce the salt contributed from approximately 600,000 irrigated acres by 1,680,000 tons annually. Average annual costs have been estimated to be $23,800,000. The unit cost for individual areas varies from a low of $5/ton/year in Grand Valley, Colorado, to a high of $12/ton/year in one small area.

In all irrigated areas salinity control works would benefit local irrigators as well as reduce the overall dissolved solids load. These benefits would be in yield increases resulting from lowering of the water table (where high water tables affect crop production), lower canal operation and maintenance costs, and reduced fertilizer costs.

Completion of all enumerated projects would result in removal of 2.8 million tons of salt annually from the Colorado River and its tributaries upstream from Hoover Dam. Approximately 22,000 acre-feet per year would be removed as brine and evaporated or injected into deep geological formations. The salts removed would amount to 25 percent of the total annual projected salt load of 11.4 million tons at Hoover Dam in the year 2000.

Cost data on these projects from open file records of the Environmental Protection Agency were available on an annual cost basis; however, data from Type I, Comprehensive Framework Studies and other sources enable close estimates to be made of the capital costs of the salinity control projects. Projects located in the Upper Colorado River Basin would have a capital cost of approximately $230 million, and those located in the Lower Colorado River Basin would have a capital cost of about $150 million.

About 79 percent of the salt reduction would be achieved from sources in the Upper Basin, while the balance would be from sources in the Lower Basin between Lee Ferry and Imperial Dam. With all projects completed, the full

reduction would amount to an average of 360 ppm under flow conditions prescribed by the Colorado River Basin Compact. Annual costs of salinity control projects divided by the estimated maximum dependable annual virgin water supply of the river, 14 million acre-feet, gives a unit cost of $3.30 per acre-foot.

Projected salinity at Hoover Dam and other major diversion points is shown in Table 9 for the years 1980, 2000, and 2030 for conditions with and without salinity control projects. The projections shown with the projects are based on the assumption that about half of the projects would be completed by 1980 and the balance by 2000.

Grand Valley, Colorado. Of the total salt load reaching Hoover Dam, 18 percent is salt pickup from Grand Valley. In 1968, the Federal Water Pollution Control Administration (now the Environmental Protection Agency) awarded a grant to the Grand Valley Water Purification Project, Inc. for the "Grand Valley Salinity Control Demonstration Project." The organization receiving the grant was a newly organized institution with board members representing the various irrigation companies in the valley. The purpose of the grant was to line canals and laterals in a demonstration area immediately east of the city of Grand Junction to determine the effectiveness of such lining in lowering the water table and decreasing the salt pickup reaching the Colorado River, which flows through the valley. The technical evaluation of the effectiveness of the lining in accomplishing the objectives of the project was subcontracted by the local organization to Colorado State University.

In evaluating the lining program, it was deemed necessary to prepare water and salt budgets for the demonstration area, as well as the entire Grand Valley. As a result, more knowledge was gained regarding on-the-farm water management and the subsurface flow system, as well as the open drain system. From this knowledge, better estimates can be prepared regarding the magnitude of the quality problem resulting from each component of the return flow system.

At the present time, plans are being developed on two fronts. First of all, when the lining program evaluation is completed in January, 1972 the demonstration area will hopefully be used to demonstrate: (a) the benefits of irrigation scheduling in improving crop yields, lowering local groundwater levels and decreasing deep percolation losses and salt pickup on a long-term basis; and (b) the advantages of tile drainage combined with careful on-the-farm water management in reclaiming poor agricultural lands, increasing crop yields and decreasing salt pickup reaching the Colorado River.

Table 9. Projected salinity in the Lower Colorado River with and without proposed salinity control projects.[a] (In Parts per Million) (8)

Station (Along Colorado River)	Average 1963-67	1980		2000		2030	
		Without Projects	With Projects	Without Projects	With Projects	Without Projects	With Projects
Below Hoover Dam	730	830	790	1,050	790	1,090	810
At Parker Dam	740	860	820	1,110	830	1,150	840
At Palo Verde Dam	[b]	910	860	1,190	890	1,230	910
At Imperial Dam	850	1,070	990	1,340	1,010	1,390	1,030
At Northerly International Boundary	1,300[c]	1,350	1,290	[d]	[d]	[d]	[d]

[a]Based on Upper Basin depletions as projected by the Colorado River Board for 1980 and the U.S.B.R. for subsequent years.

[b]Record not available.

[c]Source: International Boundary and Water Commission.

[d]Not estimated.

The second program being planned for Grand Valley involves a three-phase project which would evaluate and demonstrate the effects of irrigation practices on crop yield and salinity of irrigation return flows.

The first phase would entail studies on a small field of 30-40 acres. This intensive study area would be broken into approximately 100 plots, each having an individual drainage system. A solid-set sprinkler system will be used as the method of irrigation. Four crops - alfalfa, barley, corn, and pasture - will be studied, with the amount and timing of water application being varied for the plots, as well as nitrogen fertility levels. Bare plots will be used wherein moisture treatments are varied. In addition, special plots will be constructed which will allow a separation between salt pickup due to vertical percolation through the soil as compared with horizontal water movement along the underlying shale beds. The quantity and chemical quality of the drainage effluent from each plot will be monitored. Moisture changes and chemical quality changes will be measured in the soil profile. From these measurements, a model can be developed which describes water and salt movement through the soil. Since the drainage effluent from each plot is monitored, the model can be verified. Finally, crop yields will be measured. This phase of the program will provide relationships between moisture treatments and chemical quality of drainage effluents, thereby providing information which can be projected into a systems analysis of an area. In turn, crop production functions based on salinity levels will be developed.

The second phase of the program would utilize approximately 100 acres for a more extensive field demonstration of the effects of various irrigation methods, in combination with moisture and fertilizer treatments, on crop yield and chemical quality of irrigation return flows. This phase would make it possible to demonstrate under controlled conditions, solutions to farm problems in irrigation water management. Projections of the quantity and chemical quality of water percolating to the groundwater table will be obtained from the model developed under Phase I. This will necessitate the measurement of soil moisture and chemical quality movement through the soil profile.

The third phase of the proposed program would be the extension of recommended practices on four to six cooperative demonstration farms scattered throughout Grand Valley. These farms would be operated by their owners, but with technical assistance provided by the project.

The objective of this phase would be to demonstrate that improved farm water management can produce the desired results under farmer management, that it is practical, and that it can be profitable for the individual as well as for society generally. This phase is extremely important in obtaining farmer acceptance. Also, the feedback from the farmers is necessary so that adjustments may be made in design, operating procedures, and educational methods.

In each of the three phases, tours, seminars, publications and the news media (Grand Junction has both a local newspaper and a television station) would be used extensively to accomplish the demonstration objectives. The success of the demonstration program depends on the effectiveness with which the results are disseminated and the degree to which they are accepted and transposed into action.

The foregoing serves to illustrate one example of an approach to salinity control by improving farm water management and cultural practices in a valley area. Similar extensive investigations in other problem areas should be the basis for developing and initiating action programs designed to alleviate water quality problems arising from irrigated areas. The example also illustrates the broad spectrum approach required to formulate solutions to our present problems and also provide the necessary incentives for farmer acceptance of proven control measures. Since most of the water quality problems are area-wide in scope, the solutions to those problems must be conceived and executed on an area-wide basis.

SECTION VII

RESEARCH NEEDS

There are a multitude of research needs regarding irrigation return flow quality. The wide variety of research needs have been described in the Utah State University Foundation report, "Characteristics and Pollution Problems of Irrigation Return Flow" (30). The research needs described below are an attempt to list the specific research needs required to carry out an effective irrigation return flow quality control program. The fact that a number of important research needs are not described below only means that the priority of such needs is considered less important from the standpoint of immediate needs for getting control programs underway. The order in which research needs are discussed does not imply priority, since this may vary with regions and the difference of major problems in different irrigated areas.

Irrigation Practices

There are a number of irrigation methods now available but only surface irrigation and sprinkler irrigation are commonly used. Consequently, much of our present-day knowledge of irrigation has been derived from these methods. For surface irrigation, there is not a great need for additional research, but there is a real need to put into practice the technology now available. One of the criteria in designing a surface irrigation system is to minimize tailwater runoff, which is compatible with quality control of surface return flow. In much of the recommended research cited below, surface irrigation will frequently be used as the method of water application. In such cases, the experimental design should include studies of tailwater runoff and consequent quality degradation by sediments, phosphates, salts, fertilizers, and pesticides. In addition, experimental designs should incorporate irrigation waters of varying salinity. Efforts to automate surface irrigation systems should be encouraged.

The primary research need regarding sprinkler irrigation concerns quality degradation by sediments and the pollutants adsorbed on soil particles. Sediment erosion is particularly prevalent with high application rate sprinkler

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systems such as the center-pivot sprinkler. Design criteria which incorporate sediment erosion control are needed for sprinkler systems.

Subsurface application and drip irrigation are two methods which provide considerable control of water application timing, rates, and amount. Because of their potential for achieving high irrigation efficiencies, and increased nutrient efficiencies, these irrigation methods should be incorporated in many of the experimental designs. For example, the research needs cited below under "Soil-Plant-Salinity Relationships" could be included in some of the evaluations regarding the effectiveness of these two irrigation methods in an irrigation return flow quality control program. Also, evaluations of these irrigation methods should include water supplies covering a wide range of salinity concentrations as well as a range of soil types. In addition, the efficiency of fertilizer use should be included in the studies. Another important aspect of the experimental design would be the inclusion of information on the quantity and quality of flow which moves below the root zone. From this research, design criteria should be developed for each irrigation method which are oriented towards both the quantity and quality aspects of irrigation return flow in addition to their effects on crop yields.

Soil-Plant-Salinity Relationships

In assessing the effects of increasing the salinity of water supplies, it becomes essential that crop damage functions be determined. At the present time, we have only a fair knowledge of the salinity effects upon crop growth. We are also weak in our knowledge of crop yield functions due to water quantity, alone. Thus, experimental designs should incorporate both water quantity and quality as variables in crop production and crop damage functions. Such experiments could be incorporated in studies regarding the prediction of subsurface return flow, which are discussed later in this section.

The salt tolerance of various crops under a variety of on-the-farm water management practices should be investigated. The studies should include short-term effects due to salinity, such as the ability of a plant to withstand high salinity concentrations for short durations. Again, the salinity of the irrigation water supply should be varied. A portion of these studies could be included in the evaluation of subsurface application and drip irrigation, which are described above.

There is a tremendous potential for using slow-release fertilizers in order to maximize plant-use efficiency and minimize the quantity of fertilizer constitutents appearing in irrigation return flow. There is still a need to develop satisfactory slow-release fertilizers which will release nutrients at a rate to match plant needs. The use of slow-release fertilizers should be incorporated in many of the experimental designs on irrigation practices. In addition, demonstration projects using such fertilizers could be easily accomplished in most areas where nutrients in irrigation return flow are a problem.

The advantages of subsurface application and drip irrigation in reducing soil water evaporation should be delineated. Surface mulches and/or reduced tillage to reduce soil water evaporation could also be incorporated in demonstration projects.

After accomplishing much of the research described above, there should be a program to monitor the long-term effects of recommended irrigation and agronomic practices. Rather than just using crop yields as a measure of success, the monitoring must include water quantity and quality changes taking place in the root zone, as well as the quantity and quality changes in moisture movement below the root zone.

Leaching

Better techniques for determining optimum leaching requirements are needed. The basic problem is developing a knowledge of transport phenomena on a field basis, which can then be incorporated into the development of criteria for determining leaching requirements. The transport phenomena will involve a more detailed analysis of leaching based upon an ionic evaluation of salt movement through the soil. For example, certain salts, such as gypsum, are not really deleterious to plant growth. Consequently, if these salts are precipitated within the soil, they present no real problem. A more difficult problem results when salts such as sodium are not being leached from the root zone. Therefore, criteria for leaching should take into account the type of salts being leached, as well as total dissolved solids, as a means of evaluating leaching requirements and leaching efficiencies.

Much of our present knowledge regarding leaching requirements and the movement of water and salts in the soil has been developed in laboratory-packed columns. The results obtained under these artificial conditions can be unrealistic

when compared with undistrubed soil profiles in actual field conditions. There is a need to translate this type of information to actual field conditions, and additional studies in this area are required. The relationships between soil physical characteristics and quality of the water applied must be evaluated to determine actual leaching requirements in the real world.

Prediction of Subsurface Return Flow

The greatest single technological need at the present time for the subject area of irrigation return flow quality is the development of prediction techniques which will describe the quantity and quality of subsurface return flow. The real critical problem is defining the variability in subsurface return flows for large areas, such as an irrigated valley or a large portion of the valley.

In order to produce applicable research results, general models should be developed to describe subsurface return flow which can be adapted to numerous areas. Conceptual models must be developed and the sensitivity of various parameters which will be used in the models must be determined. In studying large areas, a balance must be reached between the sophistication of the model and the cost of collecting field data. There are still a number of limitations in our ability to make accurate field measurements. These models must be capable of predicting changes in the quantity and quality of subsurface return flows under a variety of water management alternatives. To fully evaluate chemical quality changes, the models should be capable of handling precipitation and exchange reactions which take place as the moisture moves through the soil profile. These transformations alter the ionic balance of the chemical constituents in solution and are very important in describing the quality of irrigation return flow.

Lysimeter or controlled field plot studies will be required to develop the necessary models for describing subsurface return flow. After such models have been developed, they should be verified on large areas such as an entire irrigated valley, or a major portion of an irrigated valley.

Cultural Practices

Irrigated areas containing tight soils having low permeability and receiving highly saline water supplies, which are characteristics of many irrigated valleys located at the lower end of a river system, would benefit

considerably from additional research efforts regarding soil management practices such as deep tillage or other mechanical techniques. Also, demonstration of mulching and reduced tillage to control soil water evaporation would be beneficial. Again, experimental designs for studying cultural practices could be combined with some of the research needs described below.

Irrigation Scheduling

The practice of optimum irrigation scheduling has only come about in the last few years and is presently practiced in only a few limited areas of the West. Irrigation scheduling has a tremendous potential for improving water use efficiency, with consequent improvements in irrigation return flow quality due to decreased tailwater runoff and decreased salt pickup in subsurface return flows. Because of inherent advantages to the farmer in increased crop production, this practice could overcome some of the institutional constraints in bringing about improved water management. Consequently, irrigation scheduling demonstrations could prove to be one of the best tools at our disposal for controlling irrigation return flow quality. Therefore, such demonstrations should be undertaken in the irrigated valleys of the West having major water quality problems due to irrigation return flow. Such studies must be more comprehensive than irrigation scheduling investigations to date, since the effect on the quantity and quality of subsurface return flows must be evaluated.

Pump-Back Systems

Pump-back systems for tailwater control are presently being used in certain water-short locations. Generalized design criteria should be developed for these systems which take into account sediment removal, farm salt balance, necessity for pond lining, treatment possibilities, and other environmental problems such as odors, insects, mosquitoes, etc. The effects of the recirculation of tailwater on the quality of the applied irrigation water need to be evaluated so that recommendations can be formulated for optimum design and operation criteria.

Treatment

Studies are needed to evaluate the rates of denitrification with various environments under field conditions. The studies should include management practices to control

nitrogen in the root zone. The judicious selection of soil types (i.e., those which have high denitrification potentials in the soil profile below the root zone), shallow water tables, hard pans, shallow tile drains, etc., are items which should be investigated as to conditions which might produce favorable conditions for bacterial denitrification. Alternatives for accomplishing denitrification in tile drains, or possibly open drains, should be investigated. At least partial denitrification may be accomplished in the drainage system.

The research program at Firebaugh, California provided information on nitrate reduction by algae stripping and bacterial denitrification. The results of these studies should be utilized in demonstration projects. This will also allow the costs and benefits of treatment to be compared with other alternatives for controlling water quality degradation from irrigation return flow.

Economic Evaluation

There is an ever-increasing need to delineate the wide variety of benefits and damages that occur as a result of water quality changes. In assessing costs and benefits associated with irrigation return flow, the research cited above regarding the development of crop production and crop damage functions due to water quality would provide necessary information for making more accurate economic evaluations, and consequently would also benefit the decision-making process. Along this same line, cost studies are needed for various treatment processes which may be employed to remove nutrients, sediments, and/or salts. Rather than just thinking in terms of crop production, or crop damage, resulting from water quality degradation, another important concept in economic studies should be the decreased utility of return flows to downstream water users due to deteriorating water quality.

Economic studies are needed which point out the local, state, regional, and national benefits which would accrue from the implementation, either in an irrigated valley or an entire river basin, of an irrigation return flow control program. For example, a control measure implemented in a particular valley has certain benefits to the local area, including non-agricultural sectors. The degree of quality improvement achieved by this control measure will have a number of benefits to downstream water users. Also, benefits may accrue to upstream users resulting from water exchanges or because of institutional arrangements (e.g., if standards fix the allowable water quality leaving a region, then the

improvement of irrigation return flow quality in an existing area may be required before new agricultural lands can be placed under irrigation within the region).

Institutional Changes Needed

The greatest institutional need for improving irrigation return flow quality is a change in the interpretation of western water laws to provide incentives for efficient water use. First of all, a study should be undertaken to delineate the changes in water law interpretation required to provide efficient water use incentives. Next, the procedures required to have such interpretations included in the water law structure of each state should be determined. Then, as a minimum, such changes in interpretation should be attempted in the states having major quality problems resulting from irrigation return flow. This would be particularly beneficial in a state where a control program would soon be getting underway.

Studies should be undertaken which would evaluate the possibilities of incorporating water quality into a water right (e.g., California's Water Conservation Act). For the most part, our water rights pertain only to the quantity of water. Since the quality of water can be a limitation upon its use, both quantity and quality should be specified in a water right. A variable water right based on quality may be feasible. For example, a greater quantity of low quality water will be required to produce the same results that can be obtained with a lesser amount of high quality water.

The effects of placing certain regulations upon an area in order to control irrigation return flow quality should be evaluated. For example, regulations regarding the use of fertilizers should be studied. Such studies must consider requirements for administering fertilizer regulations, as well as gaining knowledge on local and downstream benefits, along with local damages. Other regulations that need evaluation are limiting water use (e.g., use of economic charges to control water use), tailwater controls, and effluent standards for drainage systems which incorporate both quantity and quality.

Potential Control Measures

Area-wide investigations will be required in some areas to define the control measures that are needed and feasible to improve downstream water quality. The studies in the Colorado River Basin described in the previous section

(Section VI) are examples of the types required. These studies pinpoint the sources of salinity, nutrients, and other pollutants, and provide background information to support the most feasible approaches to control measures. Once the sources of pollutants are defined, more detailed studies will be required to specify how those sources may best be controlled. Such broad investigations will require the cooperative efforts of several research groups under the guidance of a central advisory committee representing local, state, and federal interests.

Local acceptance of proposed control measures will require demonstration projects and an extensive educational program to demonstrate local, regional, and interstate benefits to be gained. Considerations in implementing control programs are discussed more fully in the following section.

SECTION VIII

IMPLEMENTING CONTROL PROGRAMS

The attempt herein has been to delineate research efforts required to support an irrigation return flow quality control program. In order to spell out needed research, the possibilities for control, and consequently a control program(s), must be defined. In order to show the role of research in supporting a control program, the following discussion on implementing control programs is presented.

The initial step required in establishing any type of control program is to delineate the major types of irrigation return flow quality problems and where they occur. At the present time, the major problem areas are the Colorado River Basin, Rio Grande Basin, and San Joaquin Valley, with smaller areas like Yakima Valley and Santa Ana Basin also having critical problems.

After defining the major problem areas, the magnitude of the problem and potential solutions must be defined. Of the three major problem areas cited above, only the Colorado River Baisn has been studied on a basin-wide scale in order to develop potential solutions and costs for controlling salinity within the basin. The San Joaquin Valley has been extensively studied for purposes of agricultural development, but additional efforts on evaluating return flows are required because of the magnitude of the potential problems. There is a very strong need to undertake a study of the Rio Grande Basin to define the magnitude of the potential problems within the basin, as well as potential solutions, including costs, of controlling quality degradation. This reconnaissance study would be very similar to the type of study recently reported for the Colorado River Basin. [8,12]

Once the major problem areas within a river basin have been delineated, it then becomes necessary to conduct more detailed investigations, particularly for the areas creating the greatest quality degradation. A major problem area will likely be an irrigated valley such as Grand Valley in the Upper Colorado River Basin. At this point, it becomes necessary to investigate the water delivery system, on-the-farm water management, and the water removal system

in order to define accurately the magnitude of control possible for a number of water management alternatives. At this point, many of the research needs cited in the previous section play an important role.

The two major areas of research which would facilitate the development of control programs for an area are: (a) prediction of subsurface return flow; and (b) economic evaluation of the effects of alternative control measures. The inability at the present time to predict the quantity and quality of subsurface return flow is a real hindrance to accurately defining return flow quality changes which will result from imposing changes upon the water delivery system or improving on-the-farm water management. To overcome this lack of technology, it would appear advantageous to have a coordinated research effort utilizing recognized researchers in this area of endeavor. For instance, research projects could be initiated to study subsurface return flow in the Colorado River Basin and Rio Grande River Basin, while expanded studies are needed in the San Joaquin Valley. The projects could be coordinated by a committee consisting of recognized research leaders and state and federal personnel.

The major reason for conducting studies on subsurface return flow in each of the three major problem areas is so that the study area can be incorporated into the control program for the region. The same study area can be used for research and demonstration projects regarding irrigation practices, cultural practices, soil-plant-salinity relationships, leaching, irrigation scheduling, and treatment. Thus, there is considerable versatility in accomplishing many of the research needs. These study areas would supply the specific information needed for irrigation return flow quality control programs in that region, as well as satisfy certain general research needs applicable to other regions.

The second major area of needed activity, economic evaluation, could be accomplished in much the same manner as described above in developing prediction techniques for subsurface return flow. An economic evaluation could be undertaken for each of the three major problem areas. Again, an advisory committee could be used to conceptualize the economic models and formulate the investigations. An economic study of the benefits and damages that will result from various control measures is necessary to the control program for each major problem area. Each study can contribute to the development of general economic criteria, which can then be used in evaluating control

programs in new areas, thereby reducing the time and effort required for an economic evaluation of a new program area.

The institutional research needs could be undertaken initially without being associated with any particular study areas. The problem of instituting changes in the interpretation of western water laws primarily requires interaction with the agency in each state which administers water rights. Later, it would be desirable to define the benefits and costs in particular study areas which would result from these new interpretations.

One benefit arising from research programs conducted in the major problem areas will be the focus and attention which will be given to the problem(s). Research and associated personnel become heavily involved in the overall problems, which are then communicated to local, state, regional, and federal personnel responsible for correcting the problems. For this phase of the program to be successful, it becomes essential that a strong interaction exist between the research personnel and local and action agency personnel. First of all, there must be a strong interaction among local, state, and federal personnel in the investigations which lead to the delineation of a control program. The role of research is to supply some of the information necessary for developing the control program.

Another benefit that might result from the research program will be the possibility of training researchers and investigators in the general field of irrigated agriculture. Although there are a large number of professional people working in the field of agriculture, the number of such personnel oriented towards solving agricultural pollution problems is small. Consequently, training programs aimed at orienting a wide spectrum of professional personnel which might be associated with implementing control programs would be highly beneficial. Also, since the problems of irrigation return flow quality are world-wide, many countries would benefit by having personnel from their country receive training at the major study areas. The general technological concepts of control would essentially be the same anywhere in the world, but the institutional influences will vary considerably from one portion of the world to another.

Finally, once a specific control program has been developed for a particular area, the question arises as to the funding of the control measures. Can existing institutions be utilized, or should new institutions be developed? Since

benefits derived from control programs are not restricted locally, public support may be required to implement specific control measures.

The concept of effluent standards is presently being explored with regard to certain industrial waste effluents. It is not beyond the realm of possibility that similar approaches may be considered for agricultural wastes. Such standards would have to be concerned with pollutant loading, not just the concentrating effects. Voluntary action programs, while there is still time, would be much better for all concerned. Agricultural scientists should be aware of this and start considering the consequences of such action. Studies designed to solve a problem before enforcement action becomes necessary would be most desirable. It has already been suggested that a date for definite improvement in the quality of irrigation return flows be set. The urgency for immediate action is apparent.

Resource Requirements

Some rough estimates can be made for implementing the above mentioned studies. For example, a study involving changes in water rights interpretations for the 17 western states is estimated to have a total cost of $100,000, which could be distributed evenly between fiscal years 1973 and 1974.

A reconnaissance investigation of the Rio Grande Basin is needed to define a salinity control program. The cost of such an investigation is estimated at $250,000 per year for three years, say fiscal years 1973, 1974, and 1975. In addition, a research and demonstration site for studying irrigation methods, leaching, and subsurface return flows should be established, either in Mesilla Valley, El Paso Valley, or the Lower Rio Grande Basin. The costs for establishing such a site would be $400,000 the first year due to needed facilities, and $250,000 each succeeding year. Studies of soil-plant-salinity relationships and cultural practices should be undertaken in the Lower Rio Grande Basin at an annual estimated cost of $100,000. The economic evaluation studies should get underway the second year at an annual cost of $75,000. Also, a demonstration project involving irrigation scheduling, with roughly an annual cost of $100,000, should be underway the second year (fiscal year 1974).

In both the Colorado River Basin and San Joaquin Valley, the cost of establishing a research and demonstration site for investigating irrigation methods, leaching, and sub-

subsurface return flows would be roughly $400,000 the first year and $250,000 each subsequent year. Economic studies costing $75,000 annually, and irrigation scheduling demonstrations costing $100,000 annually, should be initiated the second year. Additional studies on soil-plant-salinity relationships and cultural practices should be encouraged in the Lower Colorado River Basin, with an estimated annual cost of $50,000.

The uniqueness of Yakima Valley, with water quality problems resulting from sediment erosion, should be utilized to develop guidelines for irrigation return flow quality control in areas subject to sediment erosion. Approximately $150,000 per year could be required to develop these guidelines.

If the above cost estimates are summarized, the total research and demonstration expenditures would amount to the totals tabulated on the following page.

	FY 73 ($1,000)	FY 74 ($1,000)	FY 75 ($1,000)	FY 76 ($1,000)
Legal Investigations	50	50		
Rio Grande Basin				
Reconnaissance Investigation	250	250	250	
Research & Dem Site	400	250	250	250
Irrigation Scheduling		100	100	100
Economic Evaluation		75	75	75
Soil-Plant-Salinity & Cultural Practices	100	100	100	100
Colorado River Basin				
Research & Dem Site	400	250	250	250
Irrigation Scheduling		100	100	100
Economic Evaluation		75	75	75
Soil-Plant-Salinity & Cultural Practices	50	50	50	50
San Joaquin Valley				
Research & Dem Site	400	250	250	250
Irrigation Scheduling		100	100	100
Economic Evaluation		75	75	75
Yakima Valley	150	150	150	150
TOTALS (in $1,000)	1,800	1,875	1,825	1,575

The rate at which resources, both professional manpower and funds, are made available to the program will determine the extent to which program objectives can be accomplished. In order to make significant inroads toward control programs, an increased level of resources will be required.

SECTION IX

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SECTION X

REFERENCES

1. Agricultural Research Service, Soil and Water Conservation Division, "Impact of Irrigation on Salinity of Surface Waters," Report submitted to the Federal Water Pollution Control Administration, USDI, Washington, D.C. (September, 1967).

2. Bain, R. C., Jr., and Marlar, J. T., "Water Quality Control Problems in Inland Sinks," Water Quality Management Problems in Arid Regions, Report 13030 DYY 6/69, Edited by James P. Law, Jr. and Jack L. Witherow, Robert S. Kerr Water Research Center, Federal Water Quality Administration, U.S. Dept. of the Interior, Ada, Oklahoma (October, 1970).

3. Blevins, R. L., Cook, D., Phillips, S. H., and Phillips, R. E., "Influence of No-tillage on Soil Moisture," Agronomy Journal, Vol. 93, No. 4, pp 593-596 (1971).

4. Bower, C. A., "Irrigation Salinity and the World Food Problem," Presented before a joint meeting of the Crop Science Society of America and Soil Science Society of America, August 22 at Stillwater, Oklahoma (1966).

5. Bower, C. A., Spencer, J. R., and Weeks, L. O., "Salt and Water Balance, Coachella Valley, California," Journal of the Irrigation and Drainage Division, ASCE, Vol. 95, No. IR1, pp 55-63 (March, 1969).

6. Carter, D. L., Bondurant, J. A., and Robbins, C. W., "Water-Soluble NO_3- Nitrogen, PO_4- Phosphorus, and Total Salt Balances on a Large Irrigation Tract," Soil Science Society of America Proceedings, Vol. 35, No. 2, pp 331-335 (March-April, 1971).

7. Casbeer, Thomas J., and Trock, Warren L., "A study of Institutional Factors Affecting Water Resource Development in the Lower Rio Grande Valley, Texas," Texas A&M University, Water Resources Center, Tech. Report No. 21, College Station, Texas (September, 1969).

8. Colorado River Board of California, "Need for Controlling Salinity of the Colorado River," Report submitted by the staff of the Colorado River Board of California to the members of the Board, Sacramento, California (August, 1970).

9. Committee on Pollution, National Academy of Sciences-National Research Council, "Waste Management and Control," Publication 1400, Report submitted to the Federal Council for Science and Technology, Washington, D.C. (1966).

10. Davenport, D. C., Hagan, R. M., and Martin, P. E., "Antitranspirants Research and Its Possible Application in Hydrology," Water Resources Research, Vol. 5, No. 3, pp 735-743 (1969).

11. Donnan, W. W., and Houston, C. E., "Drainage Related to Irrigation Management," In Irrigation of Agricultural Lands, ASA Monograph No. 11, Madison, Wisconsin. Chapt. 50, pp 974-987 (1967).

12. Environmental Protection Agency, "Summary Report," The Mineral Quality Problem in the Colorado River Basin, Regions VIII and IX (1971).

13. Faulkner, L. R., and Bolander, W. J., "Agriculturally-Polluted Irrigation Water as a Source of Plant-Parasitic Nematode Infestation," Journal of Nematology, Vol. 2, No. 4, pp 368-374 (October, 1970).

14. Federal Water Pollution Control Act (PL 84-660) as amended by Amendments of 1961 (PL 87-88), the Water Quality Act of 1965 (89-234), and the Clean Water Restoration Act of 1966 (PL 89-753), Section 1 (a).

15. Jensen, Marvin E., "Scheduling Irrigations with Computers," Journal of Soil and Water Conservation, Vol. 24, No. 5, pp 193-195 (Sept.-Oct., 1969).

16. Jensen, M. E., Robb, C. H., and Franzoy, E. C., "Scheduling Irrigations Using Climate-Crop-Soil Data," Journal of the Irrigation and Drainage Division, ASCE, Vol. 96, No. IR1, pp 25-38 (March, 1970).

17. Jensen, M. E., Swarner, L. R., and Phelan, J. T., "Improving Irrigation Efficiencies," In Irrigation of Agricultural Lands, ASA Monograph No. 11, Madison, Wisconsin. Chapt. 61, pp 1120-1142 (1967).

18. Law, J. P., Jr., "The Effect of Fatty Alcohol and a Nonionic Surfactant on Soil Moisture Evaporation in a Controlled Environment," Soil Science Society of America Proceedings, Vol. 28, No. 5, pp 695-699 (1964).

19. Moser, Theodore H., "Drainage by Pumped Wells in Wellton-Mohawk District," Journal of the Irrigation and Drainage Division, ASCE, Vol. 93, No. IR3, pp 199-208 (Sept., 1967).

20. National Technical Advisory Committee, FWPCA, "Agricultural Uses," Water Quality Criteria, U.S. Govt. Printing Office, Washington, D.C. (1968).

21. Pacific Northwest River Basins Commission, "Irrigation," Columbia-North Pacific Region Comprehensive Framework Study, Appendix IX, Vancouver, Washington (February, 1971).

22. Pavelis, George A., "Regional Irrigation Trends and Projective Growth Functions," Draft Report by Water Resources Branch, Natural Resource Economics Division, Economic Research Service, USDA, Washington, D.C. (December, 1967).

23. Pillsbury, Arthur F., and Johnston, William F., "Tile Drainage in the San Joaquin Valley of California," University of California Water Resources Center, Pub. No. 97, Los Angeles (1965).

24. Robins, J. S., "Reducing Irrigation Requirements," In Irrigation of Agricultural Lands, ASA Monograph No. 11, Madison, Wisconsin. Chapt. 62, pp 1143-1158 (1967).

25. Rohn, Arthur H., "Prehistoric Soil and Water Conservation on Capin Mesa, Southwestern Colorado," American Antiquity, 28, No. 4, pp 441-455 (1963).

26. State of California, The Resources Agency, Department of Water Resources, "Waste Water Quality, Treatment, and Disposal," San Joaquin Valley Drainage Investigation, Bull. No. 127, Appendix D, Sacramento, California (April, 1969).

27. Sylvester, Robert O., and Seabloom, Robert W., "Quality and Significance of Irrigation Return Flow," Journal of the Irrigation and Drainage Division, ASCE, Vol. 89, No. IR3, pp 1-27 (Sept., 1963).

28. U.S. Bureau of Census. 1961. U.S. Census of Agriculture: 1959.

29. U.S. Irrigated Acreage, World Irrigation, (Aug.-Sept., 1970).

30. Utah State University Foundation, Characteristics and Pollution Problems of Irrigation Return Flow, EPA (FWQA), Robert S. Kerr Water Research Center, Ada, Oklahoma (1969).

31. Wilcox, Lloyd V., "Salinity Caused by Irrigation," Journal of the American Water Works Association, Vol. 54, No. 2, pp 217-222 (February, 1962).

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16. Abstract

There are a multitude of research needs regarding irrigation return flow quality, but only the specific research needs required to undertake an effective control program are described. These research needs include irrigation practices, soil-plant-salinity relationships, leaching requirements, prediction of subsurface return flow, cultural practices, irrigation scheduling, treatment of return flows, economic evaluations, and institutional control methods.(Skogerboe-CSU)

17a. Descriptors

*Water pollution effects, *Water pollution sources, *Water quality control, fertilizers, irrigation water, nematodes, nitrates, phosphates, salinity

17b. Identifiers

*Return Flow, Irrigated Land, Irrigated Systems

17c. COWRR Field & Group 05G

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